Technical Report: NAVTRADEVCEN 1432-1

KINETIC CUEING IN SIMULATED CARRIER APPROACHES

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ABSTRACT

Pairs of matched pilots were trained using a flight simulator in a carrier-landing maneuver under two conditions — kinetic and static. The two conditions were identical, except that in the kinetic mode cockpit motion was provided. Kinetic cueing significantly improved performance in terms of percentage of successful landings, altitude error, time outside the flight path, and variability of pilot inputs. The statically trained group showed a decrement in performance which persisted throughout training and transferred to the criterion flights which involved cockpit motion. Results clearly indicate that kinetic cueing is a valuable and desirable adjunct to flight airborne simulation systems. Evidence indicates that kinetic cueing serves as a general alerter rather than as a source of specific information for the pilot.

FOREWORD

As part of a research program to increase and enhance the potential of Operational Flight Trainers (OFTs), this study was done to assess the effect of kinetic cueing in training pilots to make carrier approaches and to correct for incipient emergencies. The term kinetic cueing is deliberate and is used to designate cockpit motions that are aerodynamically accurate and kinesthetically sensed by the pilot as distinct from both random "shaker plate" motion and from motion cues provided by the visual system.

Kinetic cueing was provided by mounting the cockpit on a motion platform capable of pitch, roll, and heave, supplemented by a visual display incorporating the remaining degrees of freedom. Both kinetic and visual cueing reflected the aerodynamics of the aircraft in normal flight and in the malfunctions introduced.

Recognizing that designing motion and the associated visual display into OFT's will increase cost, we must have good hard evidence that kinetic cueing significantly and usefully enhances training. Results of this study indicate that this is precisely the case. The next step is to determine both from a training and economic standpoint, the extent and nature of motion that will satisfy the requirement.

As a by-product of this study, it was demonstrated that pilots can be given intensive practice in carrier-landing approaches by adding a motion platform and visual display to a simulator. Even in the experimental setup, with its rigorous demands for precise measurement, it was possible to maintain a rate of twenty landing approaches per hour.

All of the Appendices referred to in this summary report are included in a technical supplement, Technical Report NAVTRADEVCEN 1432-1-S1, published in a separate volume. This supplement provides, in considerable detail, descriptions of the equipment and of the experimental design plus, in like detail, the data collected.

Another study in this program is directed at the training of pilots in visual time sharing. Results are reported in Technical Report NAVTRADEVCEN 1428-1 entitled "Using a Generalized Contact Flight Simulator to Improve Visual Time Sharing."

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SECTION I

INTRODUCTION

Man's senses provide him the information necessary to adjust to his environment. He must be able to attend to this information selectively, to organize it effectively, and to react to it constructively. While the over-all process has been well identified, the functioning of individual mechanisms is far from clear. For example, there is little understanding of man's ability to select out of the many sensory inputs those that can serve as necessary and sufficient cues for action. Consider, for example, that the simple act of walking depends on cues of body position continuously fed back into the organism through both vision and proprioception (stimuli resulting from displacement of body members). Again, in speaking, both audition and proprioception are of importance. This study deals with just such a mechanism in the context of piloting an aircraft.

It is clear that in normal flight a pilot depends heavily on his visual cues. He attends consciously and consistently to these cues to make continual adjustments in control of his vehicle. It is also clear that he is continuously receiving proprioceptive cues from motion of his vehicle and changes in his body position. Yet little is known about proprioceptive cues in the context of vehicle-control. Do they help the pilot control his vehicle? If so, how much? In what way do they interact with visual cues? Do they provide specifically useful information or do they merely serve to alert the pilot to a changing state that prompts increased attention to the visual cues? Are perhaps both of these processes involved? Answers to these questions have practical as well as theoretical importance and it was the intent of this study to seek some of these answers. In seeking these answers, emphasis was placed on assessment of objectively-based performance data (as distinct from pilot-opinion data). While there is a general preference for these kinds of data, there is a specifically cogent reason for their use in this study. Simply stated, the reason is based on the fact that proprioception lacks, for the most part, the definite, conscious sensory quality typical of vision. It is relatively easier for a pilot to discuss and assess the value of the visual cues with which he is provided.

In discussing kinetic cues, he is consciously aware only of felt accelerations and is unaware of the effects of, and is unable to assess, muscle-tendon cues, labyrinthine effects, pressure changes, and other subtle, nonconscious aspects of proprioception.

With this background, the purposes of this study can be stated as an attempt: 1) to determine whether the gross effects of kinetic cueing have objectively measurable consequences upon the training of pilots to control a vehicle, and 2) to gain insight into the mechanism by which it augments the visual system, if it does.

Some elaboration is necessary to explain how these objectives were attained. The assumption was made that if kinetic cueing provided specific information, then its effect on training should be reflected by differences in performance as a function of qualitatively different motion regimes. If it acted primarily as an alerting mechanism in assisting the pilot to increase his visual attention, then all regimes should show relatively the <u>same</u> degree of improvement. If kinetic cueing is of no particular value, there should be no difference between kinetically-trained and statically-trained pilots. The regimes, with the exception of the "normal" flight, were emergency conditions that differed from each other in terms of their apparent relation to vehicular accelerations, in terms of their suddenness of onset, and in terms of the reaction required by the pilot upon detection of the emergency. The foregoing rationale was intended to provide a broad conceptual framework for the study. More detailed definition of the motion regimes and of the experimental design and procedure can be found in Section IV.

The reader is advised that Section III (as well as parts of the Supplement) provides considerably detailed descriptions of the apparatus and of the engineering aspects of the study. Those not interested in such detail can omit the reading of Section III without loss of continuity. It is sufficient that such readers accept the statement that a realistic simulation of a carrier approach was achieved.

SECTION II

LITERATURE SEARCH

Preparatory to undertaking this study, a survey of the pertinent literature was undertaken, both to minimize duplication of effort and to provide a good overview of the current level of knowledge and research sophistication. It became clear that most of the work could be classified in terms of emphasis under one of four major headings: 1) training; 2) handling characteristics; 3) human operator processes, and 4) motion dynamics (including fidelity of simulation). These headings are not meant to be mutually exclusive or all-encompassing. They do, however, serve an organizational purpose and do reflect the areas that have received major research attention.

Each citation is self-contained in that author(s), title, agency, etc., are presented in the Reference Section of the report. It is believed that this format, which is a departure from convention, is more compatible with the stated purposes (not to evaluate critically) and is actually more convenient for the reader interested in obtaining any of the reports.

Samples of studies representative of each of these major areas are presented in the remainder of this section. The annotations, as nearly as feasible, are those of the original authors.

A. MOTION CUES AND TRAINING

1. Pfeiffer, M.G., Clark, W.C., and Danaher, J.W., The Pilot's Visual Task. A Study of Visual Display Requirements, NAVTRADEVCEN Report 783-1, March 1963.

   An analysis was made of the perceptual characteristics of the pilot's visual world while performing various flight tasks. These were compared with the perceptual characteristics made available by typical nonprogrammed visual displays attached to flight trainers. An experiment was then conducted in the F-100 simulator equipped with the 151 visual attachment to determine training effects. It was determined that even among experienced subjects, performance significantly improved with regard to:

   1. The detection of inflight emergencies
   2. The maintenance of aerodynamic stability

   Recommendations are made for improvement in external visual displays to enhance the training value of flight simulators.

2. Lybrand, W.A., Havron, M.D., et al., Simulatior of Extra-Cockpit Visual Cues in Contact Flight Transition Trainers, Report AFP-TRC-58-11, February 1958.

   A survey and analysis of evidence on the visual cues utilized by pilots in performing specified flight tasks was accomplished. A serious lack of reliable, empirically derived information on the nature and functioning of extra-cockpit visual cues was found. Recommendations concern the following types of training characteristics of prototype visual attachments to flight simulators:

   1. "Flying" capability of the simulator
   2. Flight conditions to be simulated
   3. Natural and man-made objects to be visually simulated
   4. Fidelity of simulation parameters
   5. Information displays and controls of the simulator needed by the instructor for optimal training utilization.

3. Muckler, F.A., Nygaard, J.E., et al., Psychology Variables in the Design of Flight Simulators for Training, WADC Technical Report 56-369, January 1959.

   In the design, construction and utilization of such synthetic training devices as flight simulators, two general problem areas have been frequently contrasted. The first of these areas is the degree of fidelity of physical simulation. The second problem area is based on the ultimate criterion of any synthetic training device. This fundamentally is a psychological problem of transfer of training from the device to the aircraft that involves the psychological similarity between trainer and aircraft tasks; it is termed the problem of psychological simulation. The existing training research literature on flight trainers and simulators is evaluated and a number of experimental programs are suggested. Motivational, instructional, and methodological variables are considered and conventional theories of transfer of training are evaluated in terms of their predictive efficacy in the area of fidelity of psychological simulation.

4. Miller, R.G., Craig, R.C., and Purifoy, G.R., Training for Emergency Performance: I. Preliminary Report on Techniques and Recommendations for B-47 Training, Crew Research Lab., ARDC, January 1956.

The occurrence of pilot errors during B-47 flight emergencies was analyzed for contributory factors and conditions. Findings relating to detection, diagnosis, decision making, and corrective action were presented, suggesting situations and conditions to be stressed during instruction or simulated during practice.

5. Rathert, G.A., Jr., Creer, B.Y., and Douvillier, J.G.,Jr., Use of Flight Simulators for Pilot-Control Problems, NASA Memo 3-6-59A, February 1959.

Comparisons were made between actual flight results and results obtained with fixed and moving flight simulators in a number of phases of flying airplanes with a wide range of characteristics. These results were then used to study the importance of providing motion stimuli in a simulator in order that the pilot operate the simulator in a realistic manner. Regions of airplane characteristics where motion stimuli are either mandatory or desirable are indicated.

B. MOTION CUES IN RELATION TO THE HANDLING CHARACTERISTICS OF THE VEHICLE

1. Sadoff, M., McFadden, N.M., and Heinle, D.R., A Study of Longitudinal Control Problems at Low and Negative Damping and Stability with Emphasis on Effects of Motion Cues, NASA Technical Note D-348, January 1961.

   An investigation was conducted of simulated and in-flight effects of incomplete or spurious motion cues on pilot opinion and task performance over a wide range of longitudinal short-period dynamics. Tests were conducted using centrifuge-simulators. Results of a centrifuge-simulator program indicated that small positive damping was required by the pilots over most of the frequency range covered for configurations rated acceptable for emergency conditions only (e.g., failure of a pitch damper). Pilot tolerance for unstable dynamics was primarily dependent on the value of damping. Comparisons of simulator tests with flight tests indicated that the effects of incomplete or spurious motion cues provided by the simulators were important only for high frequency, lightly damped dynamics or unstable, moderately damped dynamics. Simulator studies made with an analog pilot replacing the human pilot illustrate the adaptive capability of human pilots in coping with vehicle dynamics and the control problems studied. A brief evaluation was made of a pencil-type, side-arm controller in the centrifuge.

2. Taylor, L.W., Jr., and Day, R.E., Flight Controllability Limits and Related Human Transfer Functions as Determined from Simulator and Flight Tests, NASA Technical Note D-746, May 1961.

   A simulator study and limited flight tests were performed to determine the levels of static stability and damping necessary for pilot control of the pitch, roll, and yaw attitudes of a vehicle for a short period of time Novel piloting techniques were found which enable the pilot to control the airplane at conditions that were otherwise uncontrollable. The influence on the aerodynamic coefficients and other factors, such as learning and interruption of the pilot's display, was also investigated. Information concerning human transfer functions applicable to marginally controllable tasks is presented which should aid in assessing the controllability of any specific configuration.

The existing training research literature on flight trainers and simulators is evaluated, and a number of experimental programs are suggested. Motivational instructional, and methodological theories of transfer of training are evaluated in terms of their predictive efficacy in the area of psychological simulation.

3. Brissenden, R.F., Cheatham, D.E., and Champine, R.A., Tolerable Limits of Oscillatory Acceleration Due to Rolling Motions Experienced by One Pilot During Automatic-Interceptor Flight Tests (Confidential title), NACA Research Memorandum L56K20, January 1957.

This paper presents limited data on the level of lateral oscillatory acceleration due to rolling motions found to be tolerable by a pilot during flight tests. The tests were made during the final attack phase of an automatically controlled interceptor.

4. A'Harrah, R.C., and Schulze, R.P., An Investigation of Low Altitude, High Speed Flying and Riding Qualities of Aircraft, North American Aviation, Inc. Report NA-62H-3971, February 1963.

The results of a combined flight program and ground based dynamic flight-simulator study of the handling and riding qualities problems associated with low altitude, high speed flight are presented. Wide variations of longitudinal stability and control characteristics were pilot-evaluated, and pilot performance was measured for a terrain following task flown at varying levels of atmospheric turbulence. Pilot iso-opinion mappings of longitudinal static and dynamic stability for various control systems are shown, with regions exhibiting pilot-induced oscillation PIO tendencies denoted. Pilot tolerance to gust induced acceleration is established along with the influence of stability, control, and turbulence on pilot performance.

5. Sadoff, M., A Study of a Pilot's Ability to Control During Simulated Stability Augmentation System Failures, NASA TN D-1552, November 1962.

A comparison of fixed and moving cab centrifuge results suggest that moving-cockpit flight simulators should be used for a realistic evaluation of the transient effects of stability augmenter failures since simulator motions generally interfered with the ability of the pilot to adapt to the failures. The pilot was engaged in a simple tracking task when the failure occurred. Simple pilot models are used in the analysis and prediction of the transient effects of failures.

6. Ashkenas, I.L., and McRuer, D.T., The Determination of Lateral Handling Quality Requirements from Airframe-Human Pilot System Studies, WADC TR 59-135, June 1959.

   This report represents one phase of an effort aimed at the use of the airframe-human pilot system studies as the basis for derivation of vehicle-dynamic handling qualities, specifically, lateral qualities. Tentative criteria are derived from certain roll/aileron transfer function qualities by applying existing pilot dynamic response data to servo analysis studies of the airframe-pilot system. The criteria are examined in the light of existing pilot opinion data and limited regions of validation are established. For those regions where no data exist, the tentative criteria can provide an interim basis for design and a guide to future testing.

7. Ashkenas, I.L., and McRuer, D.T., "A Theory of Handling Qualities Derived from Pilot-Vehicle System Considerations," IAS Paper 62-39, January 1962.

   The elements of the theory are presented and applied to make "predictions" about handling qualities situations which have occurred in past practice, and which may occur for some future conditions. The consequences of the theory, in terms of significant handling qualities parameters, are summarized, and probable restrictions are noted.

8. Vomaske, R.F., Sadoff, M., and Drinkwater, F.J., The Effect of Lateral-Directional Control Coupling on Pilot Control of an Airplane as Determined in Flight and in a Fixed-Base Flight Simulator, NASA TN D-1141, November 1961.

Objectives of this report are: a) To define the maximum acceptable levels of aileron-induced yawing moments; b) to assess the effect of lack of motion cues in a fixed-base flight simulator, and c) to evaluate several lateral-directional handling qualities parameters.

9. Harper, R.P., Jr., In-Flight Simulation of the Lateral-Directional Handling Qualities of Entry Vehicles, WADD TR 61-147, November 1961.

Flight evaluation of the effects of vehicle dynamic characteristics on the pilot-vehicle performance during the descent phase of flight. The evaluations are conducted in a three-axis variable stability T-33 airplane. Different sets of handling characteristics are evaluated in maneuvering flight and rated as to their suitability for the entry mission. Emphasis is placed upon the lateral handling characteristics, and 129 configurations were examined by one pilot. An effort is made to relate pilot objections and the attendant poor ratings to their causative vehicle characteristics. The piloting difficulties involved in the control of vehicles with either static or dynamic directional instabilities are discussed.

10. Sadoff, M., and Harper, C.W., A Critical Review of Piloted Flight Simulator Research, I.A.S. Report 62-186, August 1962.

Examination of a number of piloted-simulator investigations in order to assess the utility of simula-

tors for defining and solving pilot-vehicle integration and control problems of interest for various types of aircraft and spacecraft. Comparative appraisals, obtained in various ground-based simulators and in flight, are used to indicate the degree of simulator sophistication required, i.e., the visual and motion cues needed for routine handling qualities evaluations and specific control problem research.

C. MOTION CUES AND SENSING AND ACTUATING PROCESSES OF A HUMAN OPERATOR

1. Jones, C.M., Disorientation in Flight, Flying Personnel Research Committee (Great Britain) Report 96, September 1958.

   Two of the three main sources of information about orientation normally available to man, namely, the special sensations responding to linear and angular movements respectively, usually prove misleading to a pilot except in steady straight flight. This fact alone explains many cases of pilot disorientation. But it also emphasizes the supreme importance of the eyes in this context; yet even these can at times prove misleading to a pilot who is then deprived of his last resort. Experiments are described which show how this can arise during maneuvers involving a component of roll, owing to the generation of involuntary and inappropriate eye movements. It is concluded that for stability of the man-made machine combination, aerodynamics may not always be self-sufficient. Disorientation of the man can upset even the dynamically stable aircraft.

2. Young, J.W., and Barker, L.E., Jr., Moving-Cockpit-Simulator Study of Piloted Entries into the Earth's Atmosphere for a Capsule-Type Vehicle at Parabolic Velocity, NASA TN D-1797, May 1963.

   A description is presented of a moving cockpit simulator study relating to entry guidance for a low lift-drag ratio vehicle entering the earth's atmosphere at parabolic velocity. The primary goal of this study was to determine the effect of angular motions on the ability of the pilot to perform maneuvers required during supercircular entry and to compare the pilot's performance on the moving

simulator with that obtained for similar entries ᴗ a fixed base simulator. Consideration was also given to the development of a minimum instrument display for which the pilot used motion cues to aid him in performing the entry maneuvers. The study established pilot preference for the moving simulator rather than a fixed-base simulator.

3. The Human Pilot (Volume 3), Report on Fundamentals of Piloted Aircraft Flight Control Systems, BuA Report AE-61-4, August 1954.
   Describes the fundamental aspects of the sensing and actuating processes of a human pilot.

4. Brissenden, R.F., A Study of Human Pilots' Ability to Detect Angular Motion with Application to Control of Space Rendezvous, NASA TN D-1948, December 1962.
   Tests were made of light objects moving on a low intensity star background. Six subjects with normal vision participated in the tests conducted inside an inflatable 53-foot darkened radome. Various initial reference separations and rates of object motion that would be anticipated in space rendezvous were utilized.

5. Seckel, E., Traybar, J.J., and Miller, G.E., A Note on the Effect of Helicopter Dynamics on Steep Instrument Approaches, Aeronautical Eng. Report 600, February 1962.
   A series of flight tests with a number of qualified pilots and a variable stability aircraft were conducted to determine the influence on pilot opinion of certain stability parameters in steep instrument approaches in turbulence with a helicopter. The parameters varied were velocity stability, angle of attack stability, and angular damping.

6. Douvillier, J.G., Jr., Turner, H.L., et al., Effects of Flight Simulator Motion on Pilots' Performance of Tracking Tasks, NASA Technical Note D-143, February 1960.
   The effect of motion of a flight simulator on pilots' performance of a tracking task has been investigated by comparing the air-to-air tracking performance of two pilots in flight; on a motionless flight simulator, and on a flight simulator

7. Investigation of Control "Feel" Effects on the Dynamics of a Piloted Aircraft System, Report GER-6726, BuAer Report AE-61-101, April 1955.

   Experiments were conducted on a closed loop flight simulator to determine the dynamic characteristics of human operators performing a rate-control task continuously in one angular degree of freedom. The tasks resembled control of pitch or roll attitudes of aircraft during critical phases, such as attack, landing, or formation flight. A flight simulator apparatus, and aerodynamic simulator, a random-wave generator, a dynamic mock-up and a Geda Analog computer were utilized in these studies. The studies indicated that an analog computer circuit can be designed to simulate the control stick motion of any given pilot. Manual adjustment of the simulator was considered sufficiently versatile to account for individual differences and for pilot adaption to new situations. Accuracy of the simulator was sufficient to the extent that Navy pilots could not detect its substitution for themselves. A discovery was made that pilot dither is a significant part of output energy in the case of some jet interceptor pilots in a tight control task. A recommendation was made that no aircraft should be designed with low-pass aerodynamic response unless the reasons for pilot dither are understood and the inclusion of this feedback appears justified.

8. Clark, B., and Graybeil, A., "Linear Acceleration and Deceleration as Factors Influencing Nonvisual Orientation During Flight," Journal of Aviation Medicine, Vol. 20, 1959.

   This study compared actual aircraft maneuvers with interpretations of aircraft maneuvers made by a blindfolded passenger-observer. Many instances of incorrect interpretations were recorded during the study.

9. Brown, B.P., and Johnson, H.I., Moving-Cockpit Simulator Investigation of the Minimum Tolerable Longitudinal Maneuvering Stability, NASA TN-D-26, September 1959.

   Tests have been made on a moving-cockpit simulator (normal acceleration and pitch simulator) to determine the minimum tolerable maneuvering sta-

bility. Quantitative measurements of the effects of force gradient, position gradient, aircraft damping, and pitching-motion cues, with respect to a formation flying task, are presented.

10. Kreezer, G.L., Attention Value of Audio and Visual Warning Signals, WADC TR 58-521, April 1959.
    With respect to the practical problem of designing systems of warning signals, the results indicate that engineers and engineering psychologists are justified in utilizing the substantial body of knowledge already established concerning sensory thresholds, and their dependence on frequency, as a guide in the selection of stimuli to be used as warning signals.

11. Shubert, G., and Kolder, G., "Factor Analysis of Space Orientation," Revista di Medicina Aeronautica e Spaziale, Vol. 25, January 1962.
    USAF-supported experimental investigation of the contribution made by visual, otolithic, and somesthetic systems to spatial orientation, by means of a centrifuge producing acceleration up to 3g. The results show that at accelerations of up to 2.5g, visual clues are adequate for orientation; at 3g however, orientation becomes increasingly difficult. The effects of body and head position are discussed in some detail.

D. MOTION DYNAMICS AND FIDELITY OF SIMULATION OF A VEHICLE

1. Burke, R.A., A Preliminary Evaluation of the Link Visual Landing System Mark IV, Master's thesis, University of Wyoming, January 1959.
    Contents:
    - Development of Flight Training devices
    - The visual landing system
    - The nature and function of extra cockpit visual cues
    - The development of simulator training programs
    - The value of the landing system in the DC-8 simulator program
    - Recommendations on other factors affecting the value of the Visual system.

2. Haus, F.C., Czinczenheim, J., and Moulin, L., The Use of Analog Computers in Solving Problems of Flight Mechanics, AGARD-AGARDograph 44, June 1960.

The equations of motion are established for an aircraft which has a rigid structure, taking into account additional relationships introduced into the standard equations as a result of operational conditions. The bases for calculating the general equations of motion for an aircraft with a non-rigid structure are discussed. The characteristics of the motion defined by these equations are easily studied by means of analog calculations. The principles of analog calculation and the applications of such calculations to the solution of certain problems relating to the mechanics of an aircraft are presented. A number of questions concerned with the following are discussed in turn: The motion of aircraft with rigid structure; the behavior of aircraft with a nonrigid structure; the response of aircraft fitted with an automatic pilot; the calculation of landing trajectories. The automatic holding of an approach trajectory is illustrated. It is shown how analog calculations make it possible to study in detail the action of numerous parameters, and to choose from among possible solutions those which are worth adapting.

3. Muckler, F.A., Nygaard, J.E., et al., Psychology Variables in the Design of Flight Simulators for Training, WADC Report 56-369, January 1959.

In the design, construction, and utilization of such synthetic training devices as flight simulators, two general problem areas have been frequently contrasted. The first of these areas is the degree of fidelity of physical simulation that may be achieved between the flight training device and the operational aircraft. This property has been the concern of simulator design engineers, and it has been termed the problem of physical simulation. The second problem area is based on the ultimate criterion of any synthetic device: the training value that results from the use of the device. This fundamentally is a psychological problem of transfer of training from the device to the aircraft that involves the psychological similarity between trainer and aircraft tasks: it is termed the problem of psychological simulation.

4. Brown, J.L., Kuehnel, H., Nicholson, F.T., and Futterweit, A., Comparison of Tracking Performance in the TV-2 Aircraft and the ACL Computer/AMAL Human Centrifuge Simulation of this Aircraft, Report NADC-MA-6016/NADC-AC-6008, November 7, 1960.

Experimental investigation of tracking performance in a Navy TV-2 jet aircraft and in centrifuge and static simulations of the same aircraft. The opinions of subject with respect to the realism of various aspects of the simulation are summarized, and a preliminary analysis of the results, in terms of integrated error scores, is presented. Results show that work with a static or fixed-base simulator provides as good a basis for prediction of pilot performance as do investigations using a centrifuge.

SECTION III

APPARATUS

The experimental setting was physically located in two separate adjoining rooms. The simulation room housed the motion simulator and cockpit, the visual display equipment, and the necessary equipment and power to drive these devices. This room was painted dull black to minimize stray reflections and glare. The computer room housed the analog computers, tape recorders, measuring equipment and the experimenter's work area. A two-way intercommunication system was established among all test participants with the restriction that only the test director could talk to the pilot. See Fig. 1 for a complete block diagram of the system.

A. MOTION SIMULATOR

1. Degrees of Freedom

The motion simulator was located in the center of the simulation room and for this study provided acceleration cues in pitch and roll. This simulator, described in detail in Appendix A, is capable of vertical movement through ±3 ft, of roll motion through ±25°, and pitch motion through ±15°. It can be programmed for all combinations of pitch, roll and heave within the limits noted.

2. Controls

During test runs, the cockpit in which the pilots sat was enclosed in a black shroud to reduce glare and other visual distractions. The pilot had use of a control stick that produced electrical signals proportional to displacement in pitch and roll. Artificial feel was provided by nonlinear springs in both the longitudinal and lateral modes. The rudder pedal also had an artificial feel system. Detailed data on these feel systems can be found in Appendix B.

The power lever was located to the left of the pilot and used a potentiometer to produce electrical signals proportional to position. Markings alongside the arc of travel of the lever indicated to the pilot the per cent power provided by the selected position. A plot of net thrust as a function of lever position is shown in Appendix B.

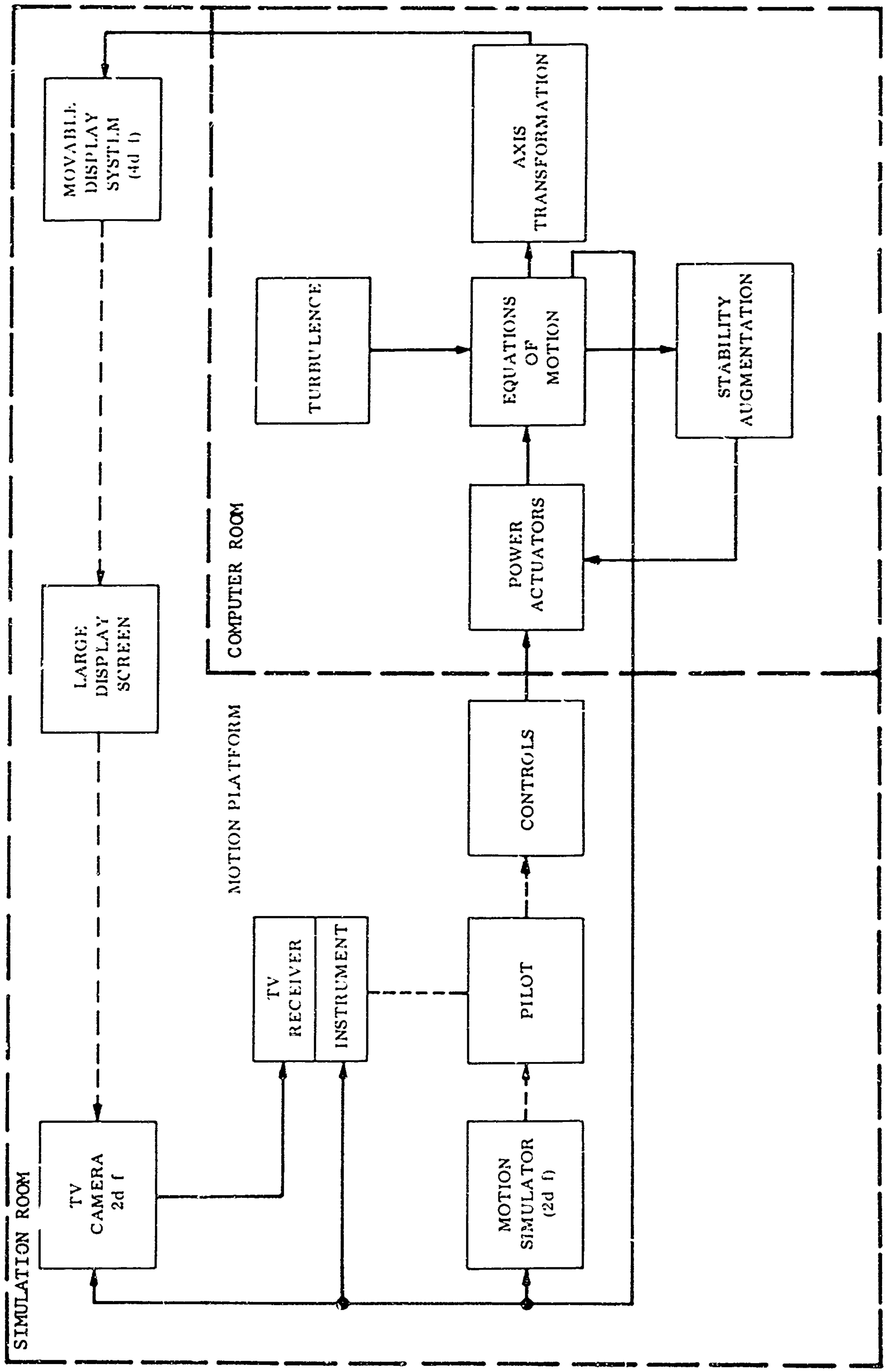

Fig. 1 Simulation Block Diagram

The vehicle was also provided with a stability augmentation system that minimized roll and pitch short period instability and effected automatic turn coordination through appropriate rudder deflections. A block diagram of the stability augmentation system will be found in Appendix C. The pilot was given selection control of the pitch and roll stabilization systems by means of toggle switches located to his left side. If he felt that the system was faulty in pitch or roll, he could switch either system off.

3. Cockpit Instrument Panel

The cockpit instrument panel (and controls) are shown in Fig. 2. The instruments include an approach flight indexer, an angle of attack indicator, vertical velocity indicator, altimeter, airspeed indicator, engine speed indicator, heading indicator, and attitude indicator. All instruments except the attitude indicator were operative and provided the pilot with accurate flight information. All except the angle of attack indicator and flight indexer are standard aircraft instruments. The angle of attack indicator is located in the upper left corner of the instrument panel. The angle of attack indexer (flight indexer) is not shown because it was located on the left side of the windshield so as to be in the pilot's field of view as he viewed the carrier. The flight indexer and indicator together with the glide slope indicator ("meatball") provided the pilot with necessary information regarding his landing configuration. The indexer measured the angle between the longitudinal axis of the vehicle and relative wind. The bar on the glide slope indicator, when centered, gave the pilot indication of the correct glide slope ($4° \pm 3/4°$). The pilot was thus provided with complete information regarding angle of attack, speed, rate of descent, and glide slope.

B. DISPLAY SYSTEM

Mounted on the cockpit approximately 2 feet in front of the pilots' eyes was a 27-inch television receiver (monitor). It presented the visual scene of a final phase of a carrier approacn that the pilots viewed (see Fig. 3). The monitor received its signals from a gimballed TV camera mounted on a stand beside the motion simulator. The camera could be programmed to pitch and roll with the same rate and direction as the motion simulator. The camera picked

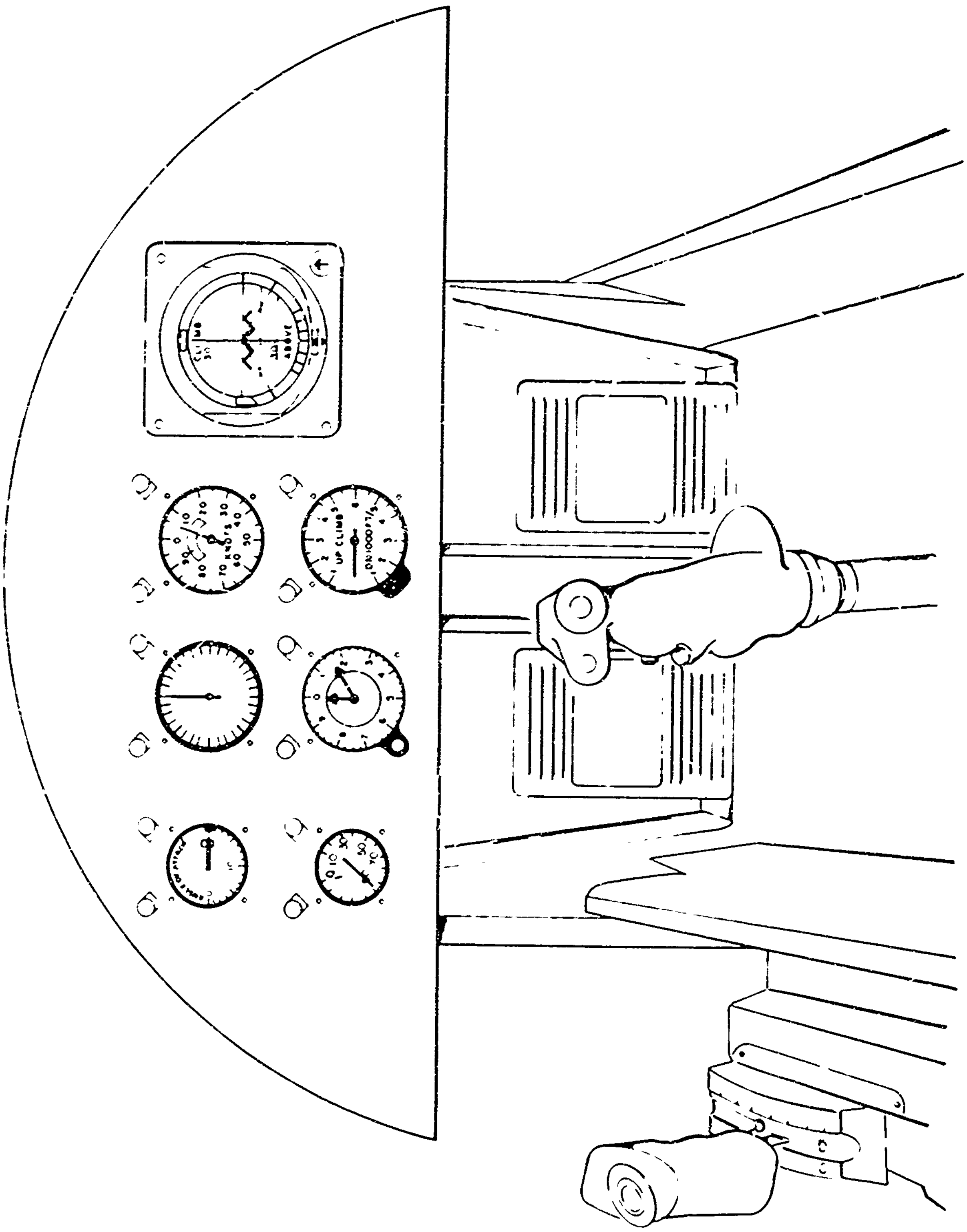

Fig. 2 Pilots Instrument Panel and Controls

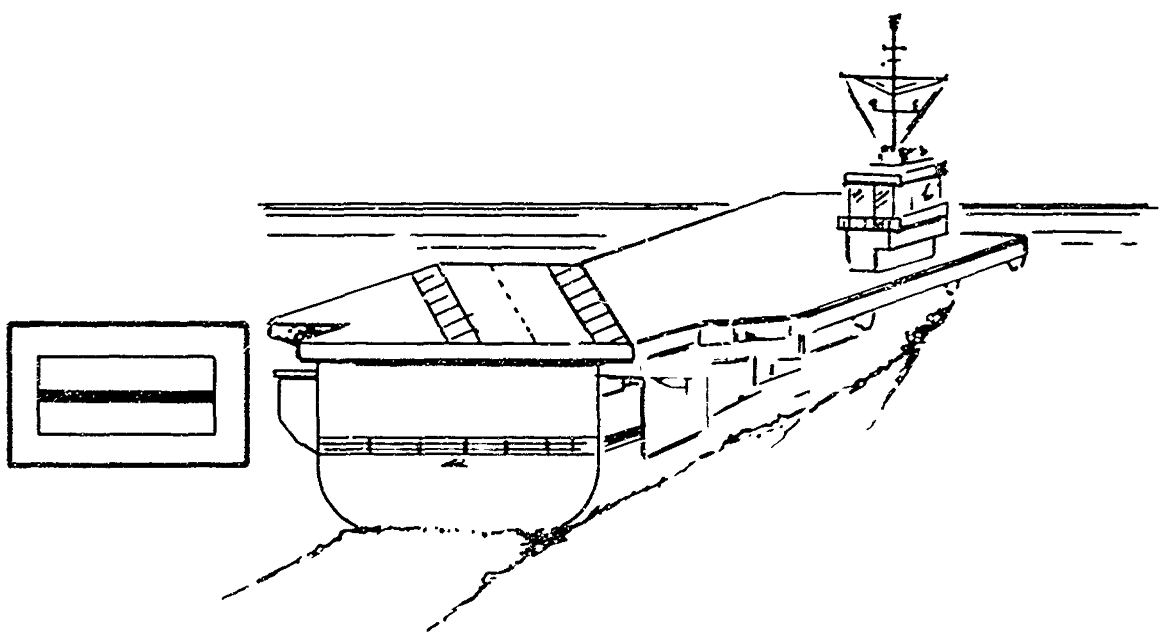

Fig. 3 Carrier Landing Approach - Pilot's View

up the picture of the carrier approach from a large screen located midway between the camera and the visual display equipment that generated the carrier scene (see Fig. 4). A model of the carrier (see Appendix D for full scale views of the model) was adhered to the highly polished mirror surface that was painted to represent a moderate sea-state. Also adhered to the mirrored surface, to the left of the carrier, was the glide slope indicator (actual size shown in Appendix D). Essentially, this indicator was a frame with a bar across it. When the bar was centered in the frame, glide slope was accurate. If the bar was high in the frame it indicated too high a glide slope and similarly if the bar was low in the frame the glide slope was too low. Sensitivity of this indicator, like an actual meatball, increased as the aircraft moved closer to the carrier. Scaling for the carrier was 1 inch equal to 127 feet. The glide slope indicator was scaled 14 times larger in order to make it visible to the pilot at the start of the flight.

A point light source provided the luminous energy for the display system. This whole system, the point light source, and the luminous plate, mounted on a carriage system, was programmed to translate in three directions and to rotate. Height was simulated by movement of the point light source; forward and side velocity and yaw were simulated by appropriate movements of the plate (refer to Fig. 4). Thus the entire visual display system provided six degrees of freedom at the monitor.

A photographic rear view of the visual system is shown in Fig. 5. A side view of the platform with the hood enclosure is shown in Fig. 6.

C. COMPUTER PROGRAMMING

A block diagram of the complete system used in simulating the carrier landing approach has been previously described and is shown as Fig. 1. As illustrated, the system can be separated into three main components, the motion platform, the display and the computer. In this section we will discuss the computer that was used to fulfill two prime functions of the study. These are: 1) control of the cockpit and displays (input), and 2) implementation of data recording and preliminary analyses (output).

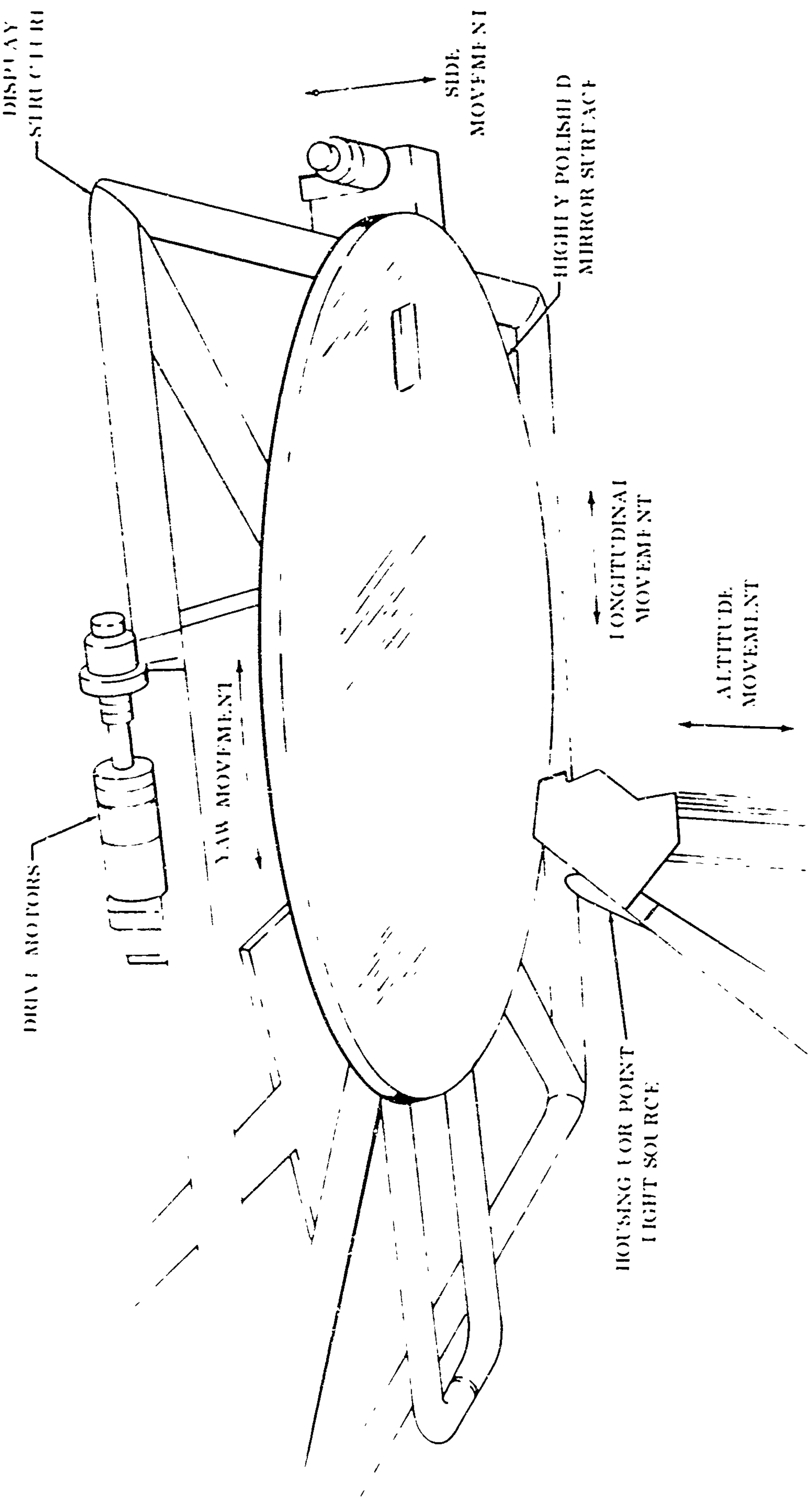

Fig. 4 Visual Display Equipment

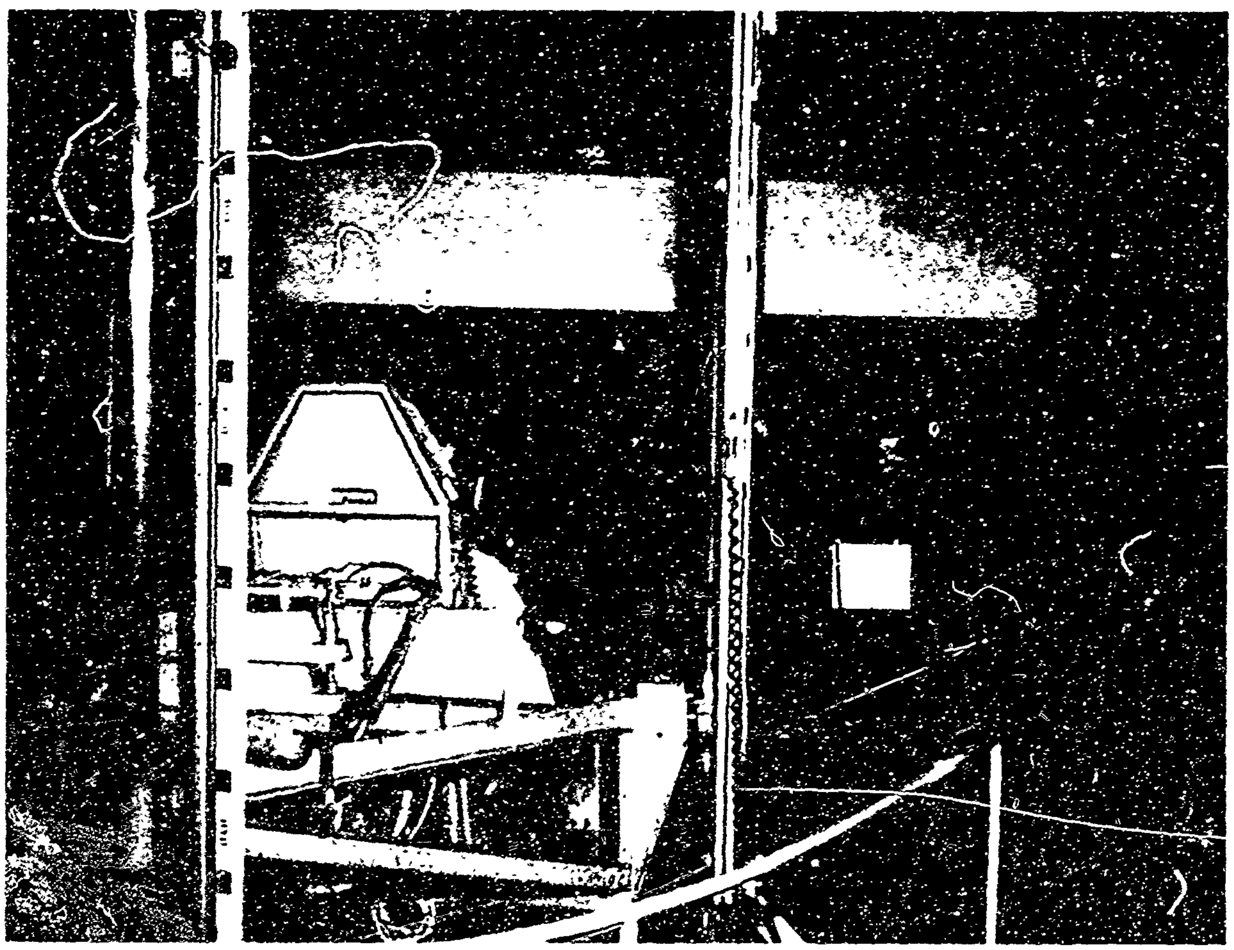

Fig. 5 Rear View of Simulation Showing Motion Platform with Hood Removed, Pilots Screen, Fixed Screen, and TV Camera (This Photograph Shows a Screen Mounted on the Cockpit that was Replaced by the TV Monitor for Actual Testing)

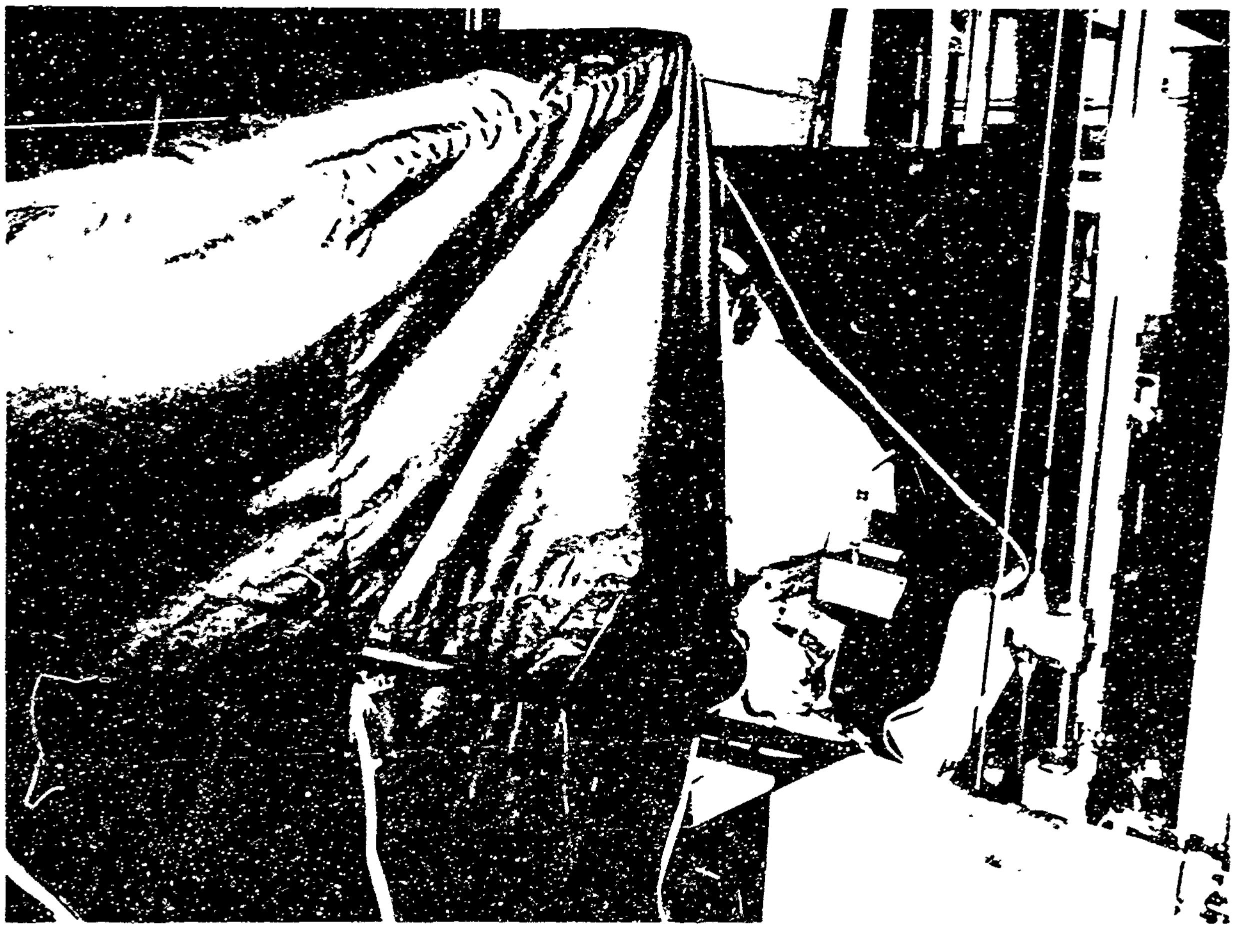

Fig. 6 Side View of Motion Platform with Black Hood Enclosure

1. Input

The first step in this process was to decide upon the type of aircraft to be simulated and to specify the equations of motions relevant to this decision. A high performance carrier-based jet vehicle was selected for reasons discussed elsewhere in this report. Detailed presentation of the equations of motion will be found in Appendix E. Computer block diagrams evolved from these equations will also be found in Appendix E; these diagrams include programs for each of the nine regimes, A through I. In the interest of realism, mild turbulence was programmed into all flights. Relevant discussion, equations, and block diagrams will also be found in Appendix E. A photograph of the computing equipment can be seen in Fig. 7.

2. Output

The second main function of the computers was the recording and preliminary analysis of data. The basic recording equipment consisted of two X-Y plotters, three eight-channel strip recorders, and five precision electric clocks. Block diagrams of the computer programs for all the recording equipment are shown in Appendix E.

Both X-Y plotters recorded time histories of each flight. Plots of a typical kinetic and static flight are shown in the upper portions of Figs. 8 and 9. One plot was of lateral displacement as a function of range. The other plot was of vertical displacement as a function of range. The glide slope of the perfect approach and the bounds on either side represent a typical mirror-controlled approach of 4° plus or minus 3/4°. On both plots, the third pendant of the carrier arrestor system is shown.

The eight-channel strip recorders were used to obtain the statistical data shown in Table 1. Samples of some of the strip chart data are also shown in Figs. 8 and 9.

All the channels of recorder 1 and the first channel of recorder 2 were used to obtain statistical data, that is, the means and root-mean squares of the variables. The remaining channels were used for recording the pilots control inputs and the corresponding aircraft response to these inputs.

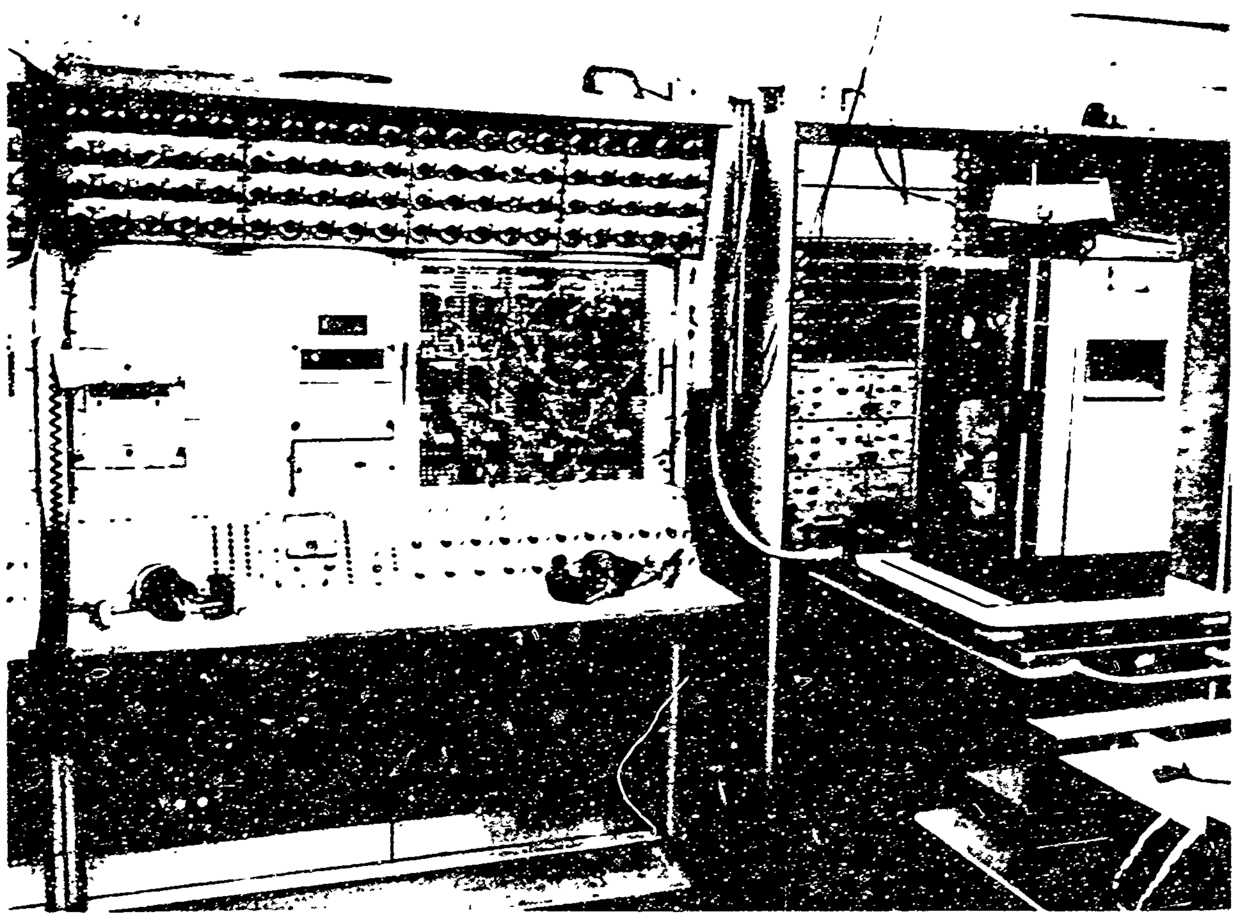

Fig. 7 View of Analog Computers Showing the Linear and Nonlinear Computers, Tape Recorder and Plotter

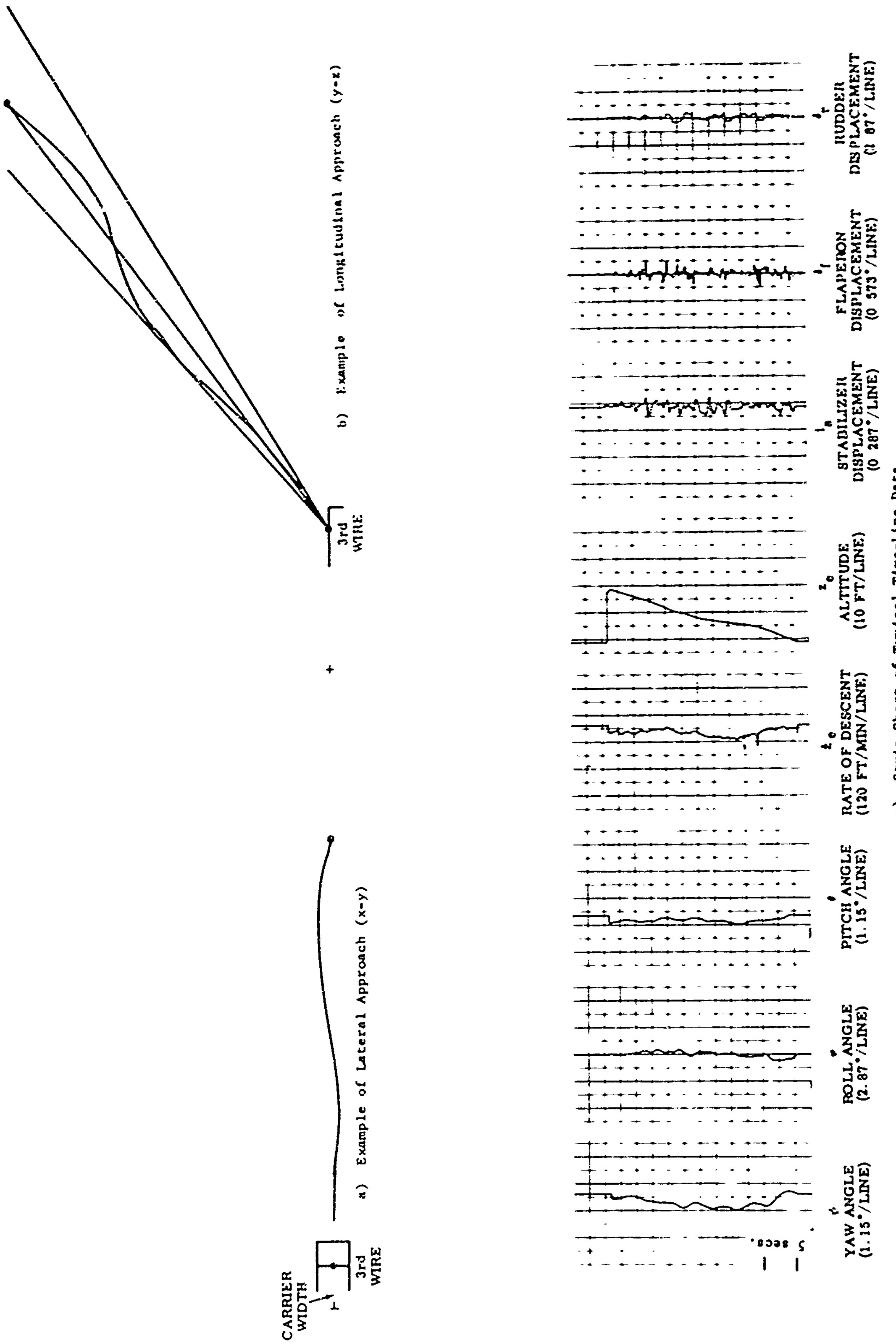

Fig. 8 Data Typical of a Kinetic Flight During Criterion Flights

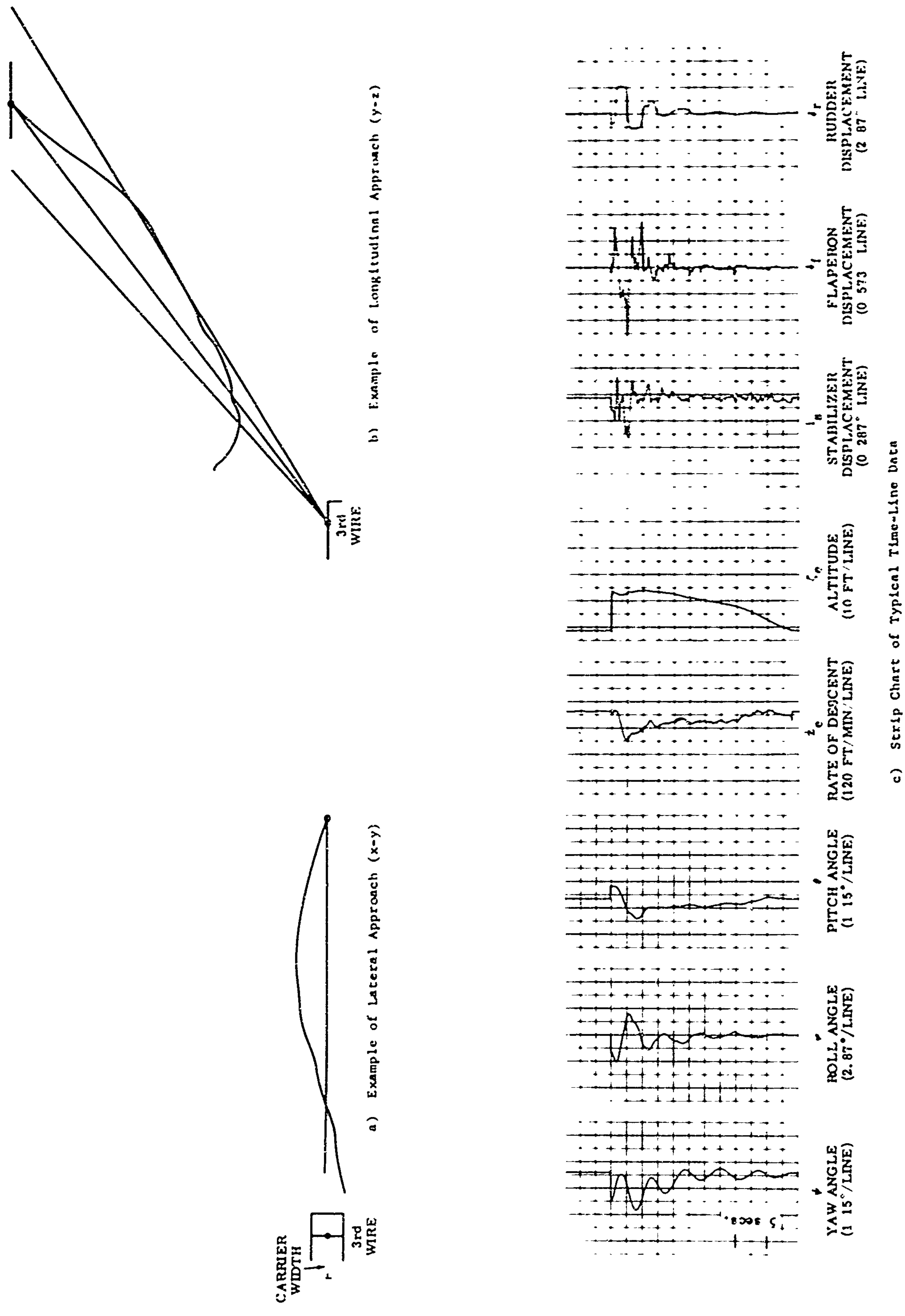

Fig. 9 Data Typical of a Static Flight During Training Flights

TABLE 1

DATA COLLECTED BY EACH CHANNEL OF THREE STRIP RECORDERS

Channels	Recorder 1	Recorder 2	Recorder 3
1	$\frac{1}{T}\int_0^T \delta_R \, dt$	$\frac{1}{T}\int_0^T \left\lvert h_e \right\rvert \, dt$	ψ [deg]
2	$\sqrt{\frac{1}{T}\int_0^T \delta_R^2 \, dt}$	p [Rad/Sec]	φ [deg]
3	$\frac{1}{T}\int_0^T \delta_\theta \, dt$	pen inoperative	θ [deg]
4	$\sqrt{\frac{1}{T}\int_0^T \delta_\theta^2 \, dt}$	q [Rad/Sec]	z_e [ft/min]
5	$\frac{1}{T}\int_0^T \Delta V \, dt$	r [Rad/Sec]	z_e [ft]
6	$\sqrt{\frac{1}{T}\int_0^T (\Delta V)^2 \, dt}$	α [Rad]	i_s [deg]
7	$\frac{1}{T}\int_0^T h_e \, dt$	β [Rad]	δ_f [deg]
8	$\sqrt{\frac{1}{T}\int_0^T h_e^2 \, dt}$	V [ft/sec]	δ_r [deg]

Five precision electrical clocks were used to obtain the following data:

a) Total time of flight

b) Time out of flight path before insertion of emergency

c) Time out of flight path after insertion of emergency

d) Time elapsed between start of flight and insertion of the emergency

e) Time the pilot detected the emergency (During early runs, pilots were instructed to depress a switch on the stick when they first detected the emergency. They found this distracting; many failed to comply. It was therefore discarded).

SECTION IV

EXPERIMENTAL DESIGN AND PROCEDURE

The previous sections of this report provided an introduction to the problem, an overview of related work, and a reasonably detailed description of the physical conditions of the experiment — the TV system, the motion simulator, the displays, the computers, and data collection equipment. This section will discuss and describe the conceptual conditions of the study. These include the basic experimental design, the mission and flight regimes, the subjects, test procedure, data collection, and analysis.

A. BASIC DESIGN OF EXPERIMENT (Serial Pick-off)

The specific experimental technique has not, to our knowledge, heretofore been used in the study of transfer of training, though an approximation to the basic paradigm is summarized in plans 1 and 4 of Woodworth and Schlosberg (Ref. 1, p. 735). Following their technique of presentation, the essential procedural elements of the experimental design can be summarized in the following steps:

1. Pairs of subjects matched on Task A (kinetic flight).

2. An interpolated task - Task B (static training) is given in varying amounts to five pairs of subjects (Group 1).

3. Continued practice (training) on Task A is given to one pair of pilots (Group 2).

4. After-test at predetermined points on Task A is given to both groups.

Another aspect of the method is touched upon by Edwards when he states: "If, for example, we were interested in change in performance over five trials and if 50 subjects were available, we might randomly assign the five levels in such a way that we have 10 subjects for each level or amount of practice. One group would be given but a single trial, another two trials, a third three trials, and so on. For each subject in each group, we would use only the final measure under the assumption that it provides an estimate of performance for a specified number of trials" (Ref. 2, p. 224). Edwards dismisses the method as being wasteful of subjects and data since all observations but the last fo each level of practice would not be used. He also states that essentially the same amount of information could be gathered by testing one group of 10 subjects on five trials. This reasoning is valid as far as it goes, and it goes no further than to apply to conditions where we are interested only in change as a function of training on the same condition. When we are interested in transfer of training, however, the method, with some variation appears more useful than conventional methods in terms of the information it affords and, in fact, permits a substantial saving in the number of subjects needed for testing.

Virtually all experiments in the area of pilot training-transfer use matched-group technique with matched groups of pilots assigned to one of the training methods. Each group is typically run through a predetermined and equal number of training sessions. Each group is then put through a number of criterion test-runs and the data analyzed to determine if performance on the criterion is affected by the treatments. Usually, the number of predetermined training sessions is based on preliminary testing or prior work, but in either case, reflects that point on the training curve to where, in the experimenter's judgment, learning has reached the apparent asymptote. The important fact to note is that this technique provides detailed data (i.e., many data points) on the progress of learning during training and relatively little data on performance on the criterion. Thus, we have most data on that part of the experiment that is of only incidental interest, and minimal data on the crucial part of the experiment.

The method used in this study places the emphasis more correctly and will hereinafter be referred to as the serial pick-off technique. As a first step in applying the method, all subjects were flown 10 times on the simulator with motion under conditions of a normal carrier flight (i.e., no emergencies inserted by the experimenter). On the basis of a matching procedure that will be described in detail in a later section of this report, 10 of the subjects (S_3 through S_{12}) were assigned to the static training group and two subjects (S_1, S_2) to the kinetic training group. Again using the matching data, the static training group was further subdivided into five subgroups of two pilots each, with each subgroup given either 3 (designated St-3 and comprising subjects S_3, S_4), 6 (designated St-6 and comprised of subjects S_5, S_6), 9 (St-9; S_7, S_8) 12 (St-12; S_9, S_{10}) or 15 (St-15; S_{11}, S_{12}) training trials on each of five motion regimes (referred to as A, B, C, D, X).[1] At the end of the designated number of static training sessions, the subjects were run three times on each of the five motion regimes on the criterion condition. The criterion condition, in this case is precisely the same condition as the training condition for the motion training group. Thus, the criterion runs for the St-3 group were compared with the comparable regimes for the second set of training runs (i.e., trials 16-30) for the K Group. The St-6 group was compared with the third set of training runs for the K Group (trials 31-45) and so on.

Table 2 is a succinct tabular summary of the basic experimental design and also shows the exact sequence of testing on each of the motion regimes for each subject.

B. TEST CONDITIONS

1. Mission

Of necessity, empirical data must be collected in the context of a specific mission. In our judgment, the carrier approach and landing seemed particularly appropriate. It is a flight operation in which pilot ability is especially taxed and one in which there is, in fact, a relatively high incidence of emergency operation. It is a clearly defined, self-contained flight operation that demands a high level of training, experience and skill on the part of the pilot. Furthermore, this mission demands precise timing and rigorous coordination and is therefore one in which early detection and prompt correction of an incipient emergency is of fundamental importance to success.

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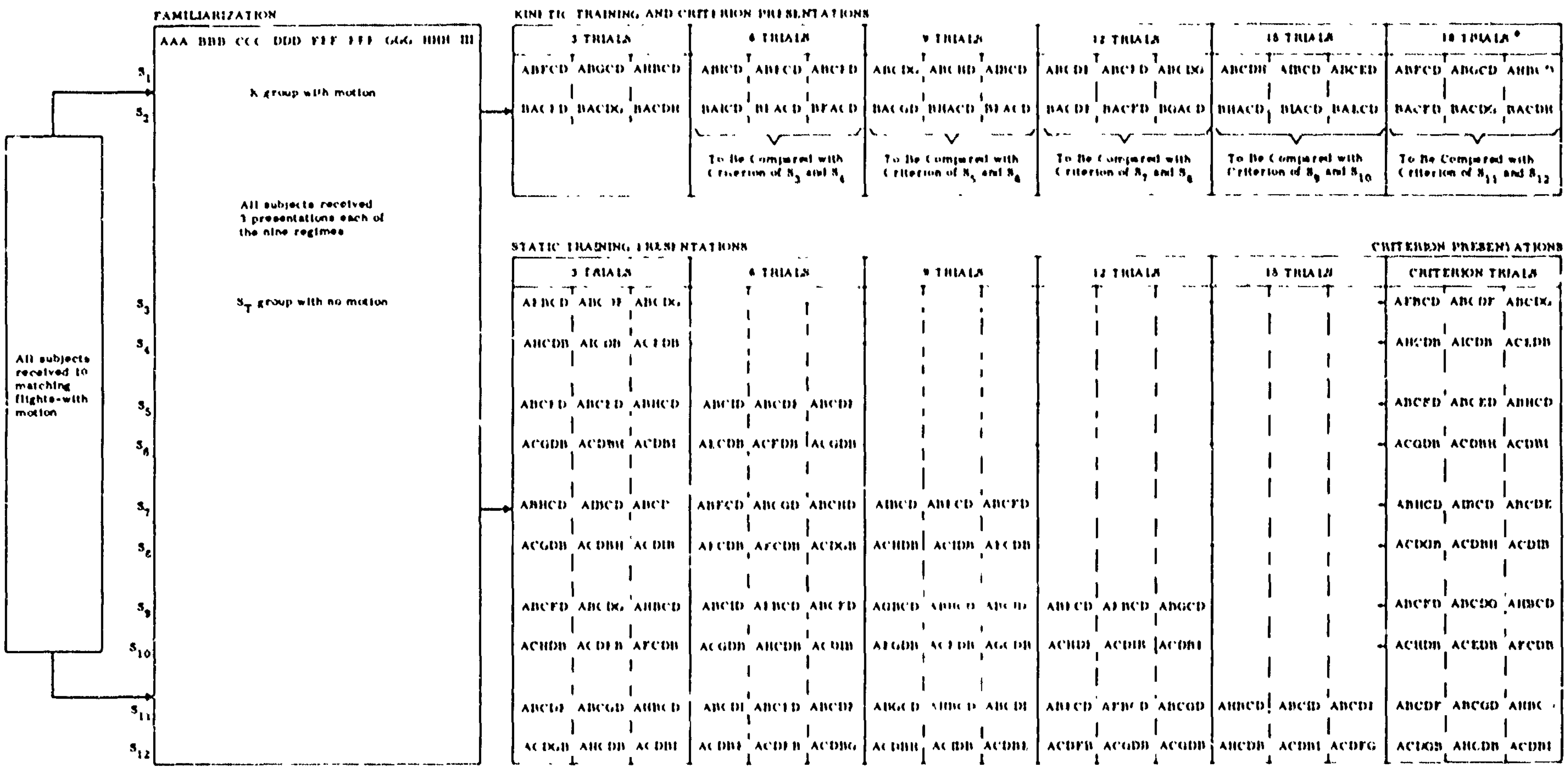
[1]Note - Definition of the regimes will be given in a later section of the report. It should be noted now, however, the "X" regime is actually a composite term used to designate regimes E, F, G, H, and I which are not themselves of experimental interest but which were included in the experiment to prevent subject familiarization with the order of presentation of the salient regimes. Thus 20 per cent of the runs were regime A, 20 per cent regime B, 20 per cent regime C, 20 per cent regime D and 20 per cent were E, F, G, H, and I.

Table 2
EXPERIMENTAL DESIGN AND TEST SEQUENCE



* These data for S_1 and S_2 were estimated

Finally, it is a mission configuration that (unlike a land-based operation) automatically serves to limit class of aircraft (and the relevant motion dynamics) that can be considered. As noted in a preceding section of this report, the vehicle simulated was a high performance, carrier-based jet aircraft.

2. Flight Regimes

The basic purpose of the study was to determine if kinetic cueing is of value in training pilots to detect emergencies. A closely related purpose was to determine if this value, if any, is tempered by the kind of emergency under consideration. It was therefore important to minimize predetermining results by selecting the emergencies very carefully. Accordingly, the emergencies were selected so as to represent a range of apparent intrinsic dependence upon motion. In addition, to avoid obviously relating the emergency to any single pilot variable, the regimes selected for study required qualitatively different pilot reactions. Thus in the three emergencies of experimental interest, the pilot's control task and reaction varied. In one ("A" failure) he was to recognize a display as faulty, ignore it, and continue to fly the vehicle normally. In another he had to detect that the automatic pitch stabilization system was faulty ("B" failure), switch it to "off," and continue to fly in his normal manner. In the third case, he had to detect a failure of the automatic power linkage ("C" failure), and correct for it by modifying his control actions. A detailed description of each of these three regimes in terms of changes in vehicle dynamics and the pilot's perceptual and decision processes is presented in Tables 3 through 5.

In addition to the three regimes mentioned, an equal number of normal flights (referred to as "D" regime) were flown by each of the pilots. Also included in the study, to control pilot-recognition of the order of presentation of regimes A through D, were five additional regimes that were presented in a randomly determined order. A description of each of these regimes follows:

E - Error bias to the upper or lower arrow of the alpha-indexer so that it could no longer be relied upon to provide accurate angle of attack information.

TABLE 3

DESCRIPTION OF THE PROCESSES INVOLVED IN THE ALPHA_INDEXER ("A" FAILURE)

Physical Manipulation	Dynamic Changes in Aircraft	Physical and Perceptual Changes in Subject	Decision Process
Alpha-indexer freezes in the "doughnut" indication	1) Closing rate too fast or too slow	1) Acceleration or deceleration onsets in labyrinthine mechanisms	1) Interpret or sense that alpha-indexer is in conflict with reality by the following determinations: a) Airspeed determination by airspeed indicator (visual cue) b) Determine if aircraft is at right pitch angle by visual cues, linear perspective of the carrier, lining up horizon and by proprioceptive cues c) Correct and monitor feedback information a) and b) until touchdown
	2) Pitch angle incorrect too high or too low	2) Changes in saccule and utricle providing sense of change in bodily position up or down	2) Interpret information as correct continue flight procedure until a change in aircraft dynamics necessitates reinterpretation of visual inputs
	3) No change in dynamic conditions Speed correct Pitch angle correct	3) Subject senses no change in average expectable environment	

TABLE 4

DESCRIPTION OF THE PROCESSES INVOLVED IN THE FAILURE OF THE AUTOMATIC PITCH STABILIZATION SYSTEM ("B" FAILURE)

Physical Manipulation	Dynamic Changes in Aircraft	Physical and Perceptual Changes in Subject	Decision Process
Pitch damper failure leading to unstable aircraft	1) Aircraft oscillates in the vertical dimension	1) Accelerations sensed by labyrinthine mechanisms indicating oscillation of body up and down 2) Visual field oscillates in coordination with aircraft and pilot	1) Sense the oscillation through the primary cues of proprioception and vision 2) Determine that the pitch damper failed 3) Switch off the pitch damper mode

TABLE 5

DESCRIPTION OF THE PROCESSES INVOLVED IN THE FAILURE OF THE AUTOMATIC THROTTLE LINKAGE ("C" FAILURE)

Physical Manipulation	Dynamic Changes in Aircraft	Physical and Perceptual Changes in Subject	Decision Process
Failure of automatic throttle linkage thereby placing the aircraft on the backside of the power curve	1) Aircraft reacts in a reverse fashion to the normal stick mode, i.e., backward stick movements lead to a drop in altitude and forward stick movements lead to sudden climb up	1) **Initial pitch change is in direction anticipated and eventually pitch changes to opposite of that expected.**	1) Determine that the aircraft has behaved in an abnormal manner
		2) Altitude changes that deviate from the expected	2) Relate the changes in pitch and altitude change to the throttle linkage failure
		3) Sensations of acceleration or deceleration of the aircraft (not possible in the simulator)	3) Readjust flying mode to compensate for this condition

F - Failure of the automatic roll stabilization system. When this occurred, the pilot was instructed to switch the system to "off."

G - Failure of all indication from the alpha-indexer. The pilot had to rely on exterior visual cues for angle of attack information.

H - Error bias in the longitudinal trim system that the pilot had to compensate for by appropriate stick force.

I - Failure of the rudder-aileron interconnect system that caused basic adverse yaw of the vehicle to be present if side forces were exerted on the stick. The pilot had to control adverse yaw by coordinating rudder pedal action with side forces on stick.

Details of the computer programs for all of the motion regimes will be found in Appendix E.

C. SUBJECTS

1. Selection and Description

Subjects were solicited by means of an advertisement placed in the Grumman PLANE NEWS and on various bulletin boards throughout the Grumman Aircraft Engineering Corporation facilities. Over 90 persons responded to the advertisements and all completed a preliminary screening questionnaire. Of this total, only 13 had flown carrier landings and the 12 most experienced were selected for inclusion in the study. For the group, total number of flying hours logged ranged from 303 to 6500 with the median number of hours 2803. Their age ranged from 29 to 45 years with the mean at 38.3 years. Three had made carrier landings within one year of the date of completing the questionnaire (November 1963); 9 of the 12 had not made a carrier landing within the three years preceding that date, though 9 had piloted an aircraft within the year. A summary of pertinent data from the questionnaire is summarized in Table 6. A copy of the questionnaire is shown in Appendix F.

Table 6

PRELIMINARY QUESTIONNAIRE DATA

SUMMARY OF REPLIES TO SELECTED ITEMS IN THE INITIAL QUESTIONNAIRE

Group Designation	Subject Designation	Total Hours Logged	Date-Last Piloted	Last Carrier Landing	Age
K	S_1	5100	Nov. 1963	1 yr	41
	S_2	3720	Dec. 1963	3+ yrs	44
St-3	S_3	2520	Jan. 1964	1 yr	35
	S_4	303	Aug. 1959	3+ yrs	29
St-6	S_5	2300	April 1964	3+ yrs	37
	S_6	1540	Nov. 1963	1 yr	31
St-9	S_7	4300	June 1963	3+ yrs	43
	S_8	1100	1961	3+ yrs	33
St-12	S_9	6500	May 1964	3+ yrs	45
	S_{10}	3094	Feb. 1958	3+ yrs	45
St-15	S_{11}	3087	Feb. 1963	3+ yrs	41
	S_{12}	2102	Feb. 1964	3+ yrs	36

2. Matching Procedure

To ensure homogeneity of variance among the six experimental blocks, the pilots were assigned to one of the blocks on the basis of three performance measures taken during the first 10 (matching) flights. These particular flights were normal ("D") approaches. Before the flights, each pilot was briefed on the purpose of the study in very general terms and instructed in the details of the controls and displays. At the end of each of these flights, each pilot was told whether the landing was successful and was given information on his maintenance of the glide slope and lateral orientation.

The measures selected for pilot-matching were mean altitude error, RMS of altitude error, and per cent of time outside the flight path. These measures were combined to provide an index of pilot proficiency. The index score for each pilot and each experimental block is summarized in Table 7. Details of the calculations are shown in Appendix G. It should be mentioned here, however, that the lower the score, the better the pilot. It should also be noted that there were no significant differences among the scores.

To further demonstrate the homogeneity of the groups, a plot of RMS stick displacement in pitch and roll for every pilot for each flight is also shown in Appendix G.

D. TYPICAL TEST SEQUENCE

At a group meeting, the volunteer pilots were advised that the purpose of the study was to assess, objectively, the effects of several training techniques on their ability to detect and control various flight emergencies. They were given a tour of the computer and simulator rooms. The controls and indication were described and the function of each explained. The pilots were requested not to discuss their specific flights and experiences with each other until all flights were completed. Individual appointments were then made with each of the pilots.

The pilot was advised that he would be making carrier landing approaches and that at the start of each flight he would be at the "window." He was then given the following command objectives:

1. Maintain proper glide slope by keeping the bar centered in the frame.

Table 7

PROFICIENCY-INDEX ON FIRST TEN MATCHING FLIGHTS

Group Designation	Subject Designation	Proficiency-Index for Subject	Proficiency-Index for Group
K	S_1	.14	.25
	S_2	.36	
St-3	S_3	.31	.41
	S_4	.51	
St-6	S_5	.20	.33
	S_6	.46	
St-9	S_7	.25	.23
	S_8	.20	
St-12	S_9	.34	.29
	S_{10}	.47	
St-15	S_{11}	.36	.29
	S_{12}	.21	

2. Maintain proper angle of attack, which would be indicated by a lighted donut on the alpha-indexer.

He was advised that imperfect glide slope or angle of attack could be due to improper rate of descent, improper speed, or improper engine setting. He was advised further that the proper settings were:

1. Speed of 105 knots

2. Power setting near 80 per cent RPM

3. Descent rate of 840 feet per minute

The pilot was then given 10 flights with full kinetic cueing and no emergency ("D" Regime). At the end of each of these flights he was told how he did with respect to glide slope and lateral orientation. Performance data from these 10 flights were then used to match the pilots and to assign them to one of the experimental blocks.

On his second appointment, each pilot was told that he would be given three flights on each of the nine motion regimes. Before the regime was described to him, he was told what to expect and what the corrective reaction should be. On each of these flights he was notified at the moment the failure was inserted and he was continuously coached during the flight. Upon completion of the flight, he was advised of his terminal position in glide slope and lateral orientation. For the kinetic group, full motion cueing was used. For the static groups, no kinetic cueing was used. After completion of the familiarization runs, the subject returned on subsequent occasions to complete his training and criterion flights. As each pilot from the static group was ready to begin his criterion flights, he was told that for the next 15 flights he would be getting the same regimes but that the simulator would now have motion in it as it had during the first 10 flights. Upon completion of the last criterion run, each pilot completed an opinion questionnaire, the results of which are discussed elsewhere in this report.

SECTION V

RESULTS AND ANALYSIS OF DATA

Each of the 10 performance measures was analyzed for differences between the kinetic and static groups during training, at the completion of training, and during the criterion flights. The analyses represent both within-group and among-group comparisons.

The performance measures can be grouped into two major categories. These are: pilot performance measures that include mean pitch, RMS pitch, mean roll, RMS roll, and measures of system performance that include per cent of time outside the flight path, mean height error, RMS of height error, mean absolute height, mean velocity, RMS velocity, and terminal flight data. The above-mentioned measures, except for terminal flight data, were each analyzed using analyses of variance. The following major classes of data were computed in this way:

1. Comparison of performance during <u>training</u> between the two main groups, kinetic and static. Results of each of the analyses will be found in Appendix H, Tables H-1 through H-50. A summary of the results of these analyses is found in Table 8, which follows.

2. Comparison of performance on the <u>criterion</u> flights between the two main groups, kinetic and static. Several of these analyses are in Appendix H.[1] The analyses of

[1] Initial analyses of variance were carried out using order of presentation as a main effect. Since, in general, there were no differences in presentation order, a decision was made to collapse presentation order to provide a better estimate of within cells error variance. Since the degrees of freedom in the error term was already large (149), computing the analysis this way makes the collapsed test more conservative and the results all the more significant. Detailed results done with the presentation order as a main effect are shown in Tables H-51 through H-62 located in Appendix H. Also located in this appendix are Tables H-63 through H-66 for the mean scores that have presentation order collapsed.

interest[1] to this study (performance after 75 training trials) are shown in Tables 9 through 18. A summary of the analysis of variance results for performance on the criterion after 60 and after 75 training trials is shown in Table 19.

The next step in the analysis and presentation of results was guided by results of the foregoing analyses of variance. As already noted, presentation order (P) did not have a significant effect on pilot performance and was therefore collapsed in subsequent analyses to inflate the error term. Moreover, it is clear from a perusal of Tables 9 through 18 that the different motion regimes (R) did not show a significant interaction effect on any of the measures. As a main effect, the regimes contributed significantly to differences on only two measures, mean velocity and RMS of stick displacement. This contrasts with the substantially larger number of differences accounted for by the training modes (M) and the training trials (T_p), each alone and in interaction. Thus, in addition to providing insight into one of the main questions of this study, it also appeared to be adequate justification for simplifying subsequent t-test analyses of the data and graphic presentation of results. Accordingly, since each pair of pilots flew each of five regimes either 3, 6, 9, 12, or 15 times, and since regimes were not a significant factor, each pair can be considered to have flown either 15, 30, 45, 60, or 75 training flights. The abscissa on each

[1] Due to an oversight, empirical data for performance of the kinetic group on the criterion <u>after</u> 75 training trials were not collected. Data for this point were estimated by taking the mean increment of values for performance on the criterion (after 15, 30, 45, and 60 training trials) and algebraically adding this to the last point on the criterion. An analysis was carried out on these data and on the same data with the 75 trial point dropped from the analysis (Tables H-51 through H-66 , Appendix H). No substantial differences between the two analyses developed. Therefore the body of this report deals with the data containing the estimated point for the kinetic group.

Table 8

SUMMARY OF ANALYSES OF VARIANCE RESULTS
FOR 10 PERFORMANCE MEASURES GROUPED BY NUMBER OF
TRAINING TRIALS

Measure	TRIALS				
	15	30	45	60	75
% Time Outside of Flight Path	N. S.	N. S.	M**	N. S.	M*
Mean Stick Displacement in Roll	N. S.	N. S.	N. S.	N. S.	N. S.
RMS of Stick Displacement in Roll	M**	M**	M**	M** RxT_p*, $MxRxT_p$*	M**, R** MxR**
Mean Stick Displacement in Pitch	M**	M** $MxRxT_p$**	M**	N. S.	M**, MxT_p**
RMS of Stick Displacement in Pitch	M**	M**	M**	M**, R* MxT_p*	M**
Mean Velocity	M**	M**	M**	M**	M**
RMS of Velocity	N. S.	N. S.	N. S.	N. S.	M*
Mean Height Error	N. S.	N. S.	M* MxT_p*	M**, T_p*	N. S.
RMS of Height Error	N. S.	N. S.	M**	R*	N. S.
Absolute Height Error	N. S.	M*	MxT_p**, M**, R*	N. S.	M*, R*

All analyses of the means are with presentations taken out as a main effect.
See text on page 45 for legend.

** $p < .01$ NS - Not significant Tp - Training Trials

* $p < .05$ M - Modes R - Motion Regimes

Table 9

ANALYSIS OF VARIANCE OF MEAN STICK DISPLACEMENT IN PITCH DURING CRITERION FLIGHTS[1]

Source	df	MS	F
Training Mode (M)	1	1.27	59.91**
Motion Regime (R)	4	.006	-
Training Trials (T_p)[2]	4	.034	1.60
MxR	4	.008	-
MxT_p	4	.156	7.36**
RxT_p	16	.027	1.27
$MxRxT_p$	16	.010	-
Between	5	.106	
Residual	245	.021	

[1]Represents analysis after 15, 30, 45, 60 and 75 training trials (criterion data for the kinetic group after 75 training trials is extrapolated).

[2]Note---T_p = Presentation order collapsed.

**$p < .01$

*$p < .05$

Table 10

ANALYSIS OF VARIANCE OF RMS OF STICK DISPLACEMENT IN PITCH DURING CRITERION FLIGHTS[1]

Source	df	MS	F
Training Mode (M)	1	2.72	93.79**
Motion Regime (R)	4	.165	5.69**
Training Trials (T_p)[2]	4	.069	2.38
MxR	4	.010	-
MxT_p	4	.017	-
RxT_p	16	.023	-
$MxRxT_p$	16	.022	-
Between	5	.258	
Residual	245	.029	

[1]Represents analysis after 15, 30, 45, 60 and 75 training trials (criterion data for the kinetic group after 75 training trials is extrapolated).

[2]Note---T_p = Presentation order collapsed.

$^{**}p < .01$
$^{*}p < .05$

Table 11

ANALYSIS OF VARIANCE OF MEAN STICK DISPLACEMENT IN ROLL DURING CRITERION FLIGHTS[1]

Source	df	MS X 10^{-4}	F
Training Mode (M)	1	.270	-
Motion Regime (R)	4	11.84	1.43
Training Trials (T_p)[2]	4	52.95	6.41**
MxR	4	4.76	-
MxT_p	4	8.34	1.01
RxT_p	16	7.15	-
MxRxT_p	16	6.09	-
Between	5	7.72	
Residual	245	8.24	

[1] Represents analysis after 15, 30, 45, 60 and 75 training trials (criterion data for the kinetic group after 75 training trials is extrapolated).

[2] Note---T_p = Presentation order collapsed.

** $p < .01$
* $p < .05$

Table 12

ANALYSIS OF VARIANCE OF RMS OF MEAN STICK DISPLACEMENT IN ROLL DURING CRITERION FLIGHTS[1]

Source	df	MS	F
Training Mode (M)	1	.028	1.65
Motion Regime (R)	4	.027	1.59
Training Trials (T_p)[2]	4	.313	18.41**
MxR	4	.018	1.06
MxT_p	4	.273	16.06**
RxT_p	16	.009	-
$MxRxT_p$	16	.009	-
Between	5	.103	
Residual	245	.017	

[1]Represents analysis after 15, 30, 45, 60 and 75 training trials (criterion data for the kinetic group after 75 training trials is extrapolated).

[2]Note---T_p = Presentation order collapsed.

**$p < .01$

*$p < .05$

Table 13

ANALYSIS OF VARIANCE OF PER CENT OF THE OUTSIDE OF FLIGHT PATH DURING CRITERION FLIGHTS [1]

Source	df	MS	F
Training Mode (M)	1	.646	17.23**
Motion Regime (R)	4	.039	1.04
Training Trials (T_p)[2]	4	.182	4.85**
MxR	4	.041	1.09
MxT_p	4	.069	1.84
RxT_p	16	.036	-
$MxRxT_p$	16	.042	1.12
Between	5	.080	
Residual	245	.038	

[1] Represents analysis after 15, 30, 45, 60 and 75 training trials (criterion data for the kinetic group after 75 training trials is extrapolated).

[2] Note ---T_p=Presentation order collapsed

**$p < .01$

*$p < .05$

Table 14

ANALYSIS OF VARIANCE OF MEAN ABSOLUTE HEIGHT ERROR DURING CRITERION FLIGHTS[1]

Source	df	MS	F
Training Mode (M)	1	934.79	30.10**
Motion Regime (R)	4	46.76	1.51
Training Trials (T_p)[2]	4	156.05	5.02**
MxR	4	38.63	1.24
MxT_p	4	56.09	1.81
RxT_p	16	31.52	1.01
$MxRxT_p$	16	20.66	-
Between	5	72.64	
Residual	245	31.10	

[1] Represents analysis after 15, 30, 45, 60 and 75 training trials (criterion data for the kinetic group after 75 training trials is extrapolated).

[2] Note---T_p = Presentation order collapsed.

** $p < .01$
* $p < .05$

Table 15

ANALYSIS OF VARIANCE OF MEAN HEIGHT ERROR
DURING CRITERION FLIGHTS[1]

Source	df	MS	F
Training Mode (M)	1	.250	-
Motion Regime (R)	4	185.14	2.33
Training Trials (T_p)[2]	4	725.25	9.14**
MxR	4	32.65	-
MxT_p	4	35.22	-
RxT_p	16	115.86	1.46
$MxRxT_p$	16	102.60	1.29
Between	5	64.25	
Residual	245	79.60	

[1]Represents analysis after 15, 30, 45, 60 and 75 training trials (criterion data for the kinetic group after 75 training trials is extrapolated).

[2]Note---T_p = Presentation order collapsed.

**$p < .01$
*$p < .05$

Table 16

ANALYSIS OF VARIANCE OF RMS OF HEIGHT ERROR DURING CRITERION FLIGHTS[1]

Source	df	MS	F
Training Mode (M)	1	320.82	3.95
Motion Regime (R)	4	67.85	-
Training Trials (T_p)[2]	4	379.52	4.67**
MxR	4	54.81	-
MxT_p	4	90.52	1.11
RxT_p	16	81.28	-
MxRxT_p	16	71.71	-
Between	5	159.68	
Residual	245	81.97	

[1]Represents analysis after 15, 30, 45, 60 and 75 training trials (criterion data for the kinetic group after 75 training trials is extrapolated).

[2]Note---T_p = Presentation order collapsed.

**$p < .01$

*$p < .05$

Table 17

ANALYSIS OF VARIANCE OF MEAN VELOCITY ABOUT A NOMINAL VALUE DURING CRITERION FLIGHTS[1]

Source	df	MS	F
Training Mode (M)	1	2261.55	185.22**
Motion Regime (R)	4	52.14	4.27**
Training Trials (T_p)[2]	4	118.51	9.71**
MxR	4	27.38	2.24
MxT_p	4	126.36	10.35**
RxT_p	16	11.17	-
MxRxT_p	16	15.08	1.23
Between	5	115.08	
Residual	245	12.21	

[1] Represents analysis after 15, 30, 45, 60 and 75 training trials (criterion data for the kinetic group after 75 training trials is extrapolated).

[2] Note---T_p = Presentation order collapsed.

** $p < .01$
* $p < .05$

Table 18

ANALYSIS OF VARIANCE OF RMS OF VELOCITY ABOUT A NOMINAL VALUE DURING CRITERION FLIGHTS[1]

Source	df	MS	F
Training Mode (M)	1	22.67	1.66
Motion Regime (R)	4	32 15	2.36
Training Trials (T_p)[2]	4	99.32	7.30**
MxR	4	8.94	-
MxT_p	4	113.55	8.33**
RxT_p	16	11.21	-
$MxRxT_p$	16	9.33	-
Between	5	96.73	
Residual	245	13.63	

[1]Represents analysis after 15, 30, 45, 60 and 75 training trials (criterion data for the kinetic group after 75 training trials is extrapolated).

[2]Note---T_p = Presentation order collapsed.

**$p < .01$

*$p < .05$

Table 19

SUMMARY OF ANALYSIS OF VARIANCE RESULTS
FOR 10 PERFORMANCE MEASURES ON CRITERION FLIGHTS

Measure	Significant Factors: 75 Trials[1,2]	Significant Factors: 60 Trials[3]
% Time Out of Flight Path	M**, T_p**	M**, T* MxT*
Mean Stick Displacement in Roll[2]	T_p**	N.S.
RMS of Stick Displacement in Roll	T_p**, MxT_p**	T**, MxT**
Mean Stick Displacement in Pitch[2]	M**, MxT_p**	M**, MxT_p**
RMS of Stick Displacement in Pitch	M**, R**	M**, T**
Mean Velocity[2]	M**, R**, T_p** MxT_p**	M**, T_p** MxT_p**
RMS of Velocity	T_p**, MxT_p**	M*, T*
Mean Height Error[2]	T_p**	R*
RMS of Height Error	T_p**	T**, P* MxP*
Absolute Height Error	M**, T_p**	M**, T**

1 75 trials contains extropolation for last 15 trials of kinetic group.

2 These analyses all have "presentations" collapsed.

3 The analyses have "presentations" collapsed for mean scores only.

** $P < .01$

* $P < .05$

of the following graphs reflects this presentation of the data. The "a" subscripted graphs in Figs. 10 through 19 are presentations of the performance of the static groups during their corresponding training trials. For each matched group (St-6, St-9, etc.), the level of performance reached at termination of their prescribed level of training is depicted in the "b" subscripted graphs.[1] The "b" subscripted graphs also denote performance during training for the kinetic group. The "c" subscripted graphs show performance on 15 criterion flights for both main groups after the specified level of training (noted on the abscissa).

When the t-test analyses and related symbology are explained, the reader will be prepared to read Figs. 10 through 19 with complete understanding. For the training curves (in the "a" subscripted figures), t-tests were computed for each training group (St-6, St-9, etc.) at their successive levels of training. For example, the St-9 group's score on each performance measure at 15 trials was compared to its score at 30 trials and at 45 trials. The score at 30 trials was compared to the one of 45 trials. Where differences occur they are denoted on the graph in the manner explained in the legend below.

The endpoints of each static training group (dashed lines in "b" subscripted figures) were also compared to each other by t-values (see Appendix J, Tables J-1 through J-10 for means and t-values). Similarly, t-values were computed for the kinetic group (solid lines on "b" subscripted graphs; means and t-values are in Appendix J, Tables J-1 through J-10). Again, t-values were calculated for the mean performance scores for the two main groups during their criterion flights, as a function of the level of training (see Appendix J, Tables J-11 through J-20 for means and t-values). The foregoing t-tests, described in this paragraph, are referred to as intertrial t-tests. In addition, t-tests were calculated between the mean scores of the two main groups at successive levels of training

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[1] The "a" subscripted graphs do not show a point for the St-3 group since this is a single point and alone could give no indication of learning trend, if any, during training. The level of performance reached during training for the St-3 group is the first point on the "b" subscripted graphs for the static group.

during their training flights (see Appendix J, Tables J-21 through J-30) and during their 15 criterion flights (see Appendix J, Tables J-31 through J-40). These are referred to as the between-group t-tests.

All salient results of the t-tests are summarized on the graphs. The reader has only to retain in mind the legend shown in Table 20.

Table 20

LEGEND FOR INTERPRETATION OF SYMBOLS ON FIGS. 10 THROUGH 19

○	(Around number of Trials) indicates a statistically significant difference between the static and kinetic groups at that point.
•	Not significantly different from preceding point.
X	Significantly different from all preceding points.
□	Significantly different from one or more of the preceding points but not the one immediately preceding it.
△	Significantly different only from the point immediately preceding it.
◇	Significantly different from the point immediately preceding it and one or more preceding points.

A. PILOT PERFORMANCE MEASURES

1. Mean Stick Displacement in Pitch

The first point to notice in Fig. 10a is the absence of any indication of learning for any of the pilots in the static groups. The comparable curve for the kinetic group (Fig. 10b) does show one significant difference after 75 training trials with motion cueing. It should be noted, however, that this difference is in a direction away from improvement in performance. The slope of the curve should be upward from the K-15 point if improvement were occurring because optimum pitch was determined to be .36 inches. This

See page 59 for Symbol Legend

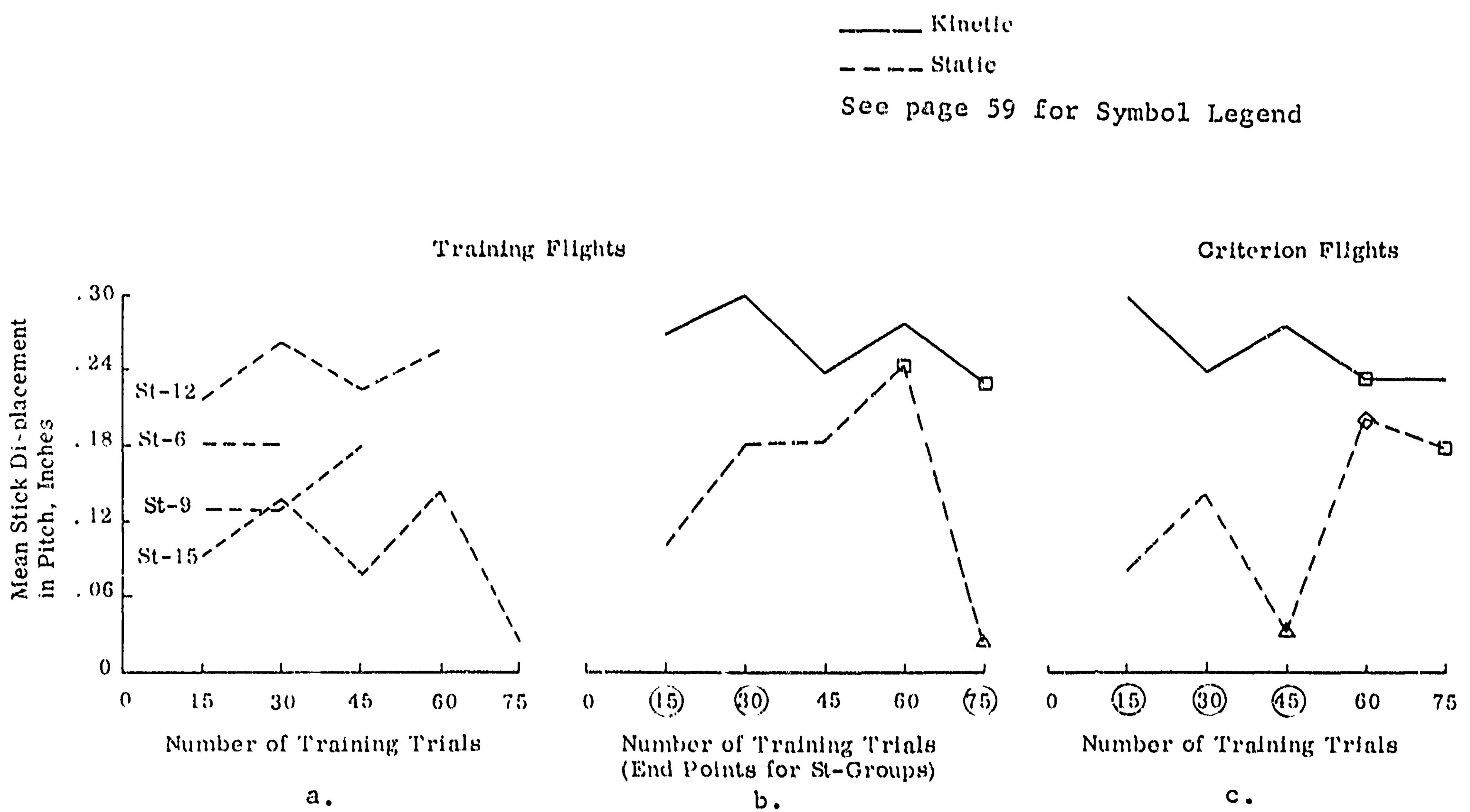

Fig. 10 Mean Stick Displacement in Pitch During Training and Criterion Flights.

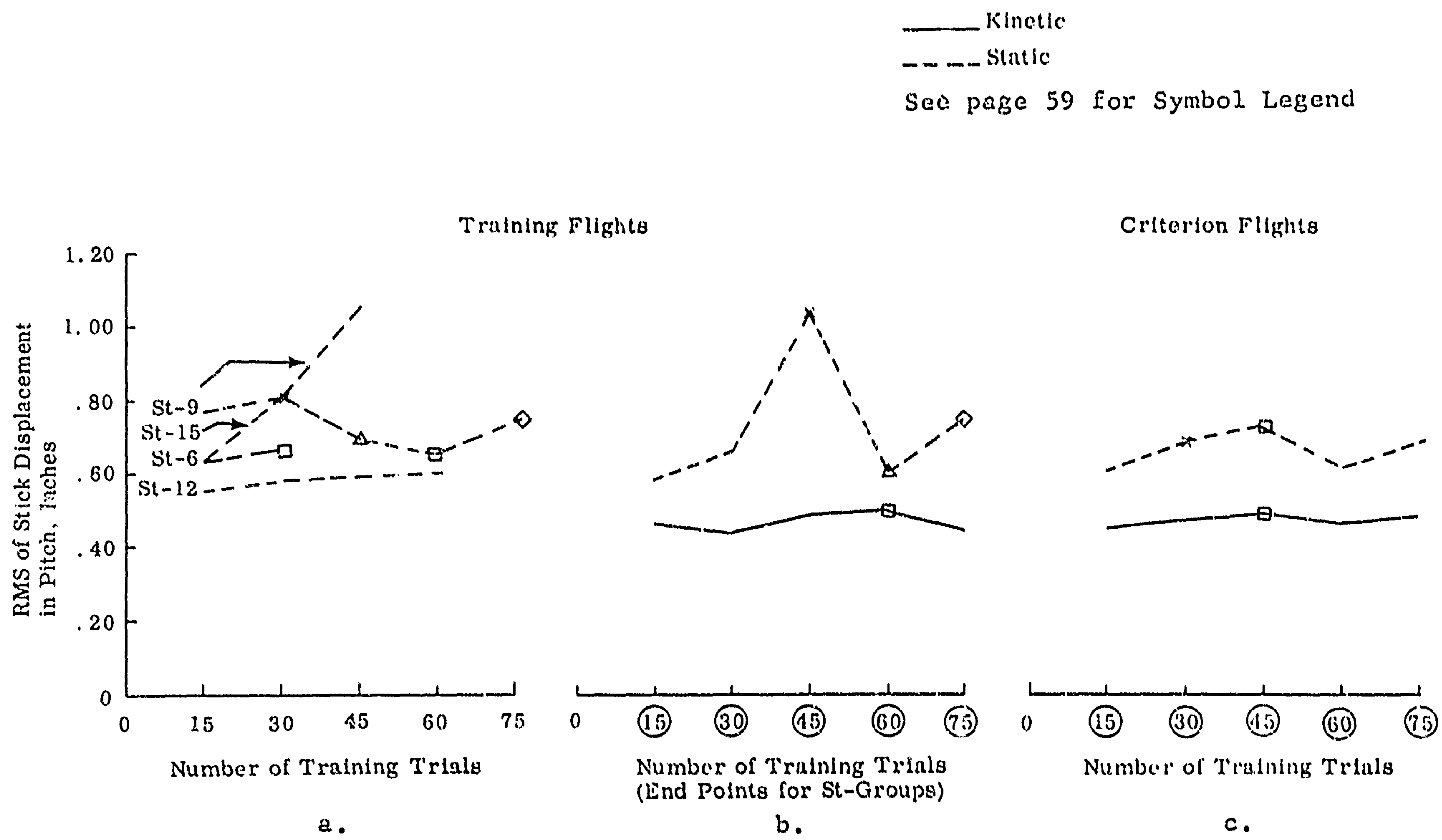

Fig. 11 RMS of Stick Displacement in Pitch During Training and Criterion Flights.

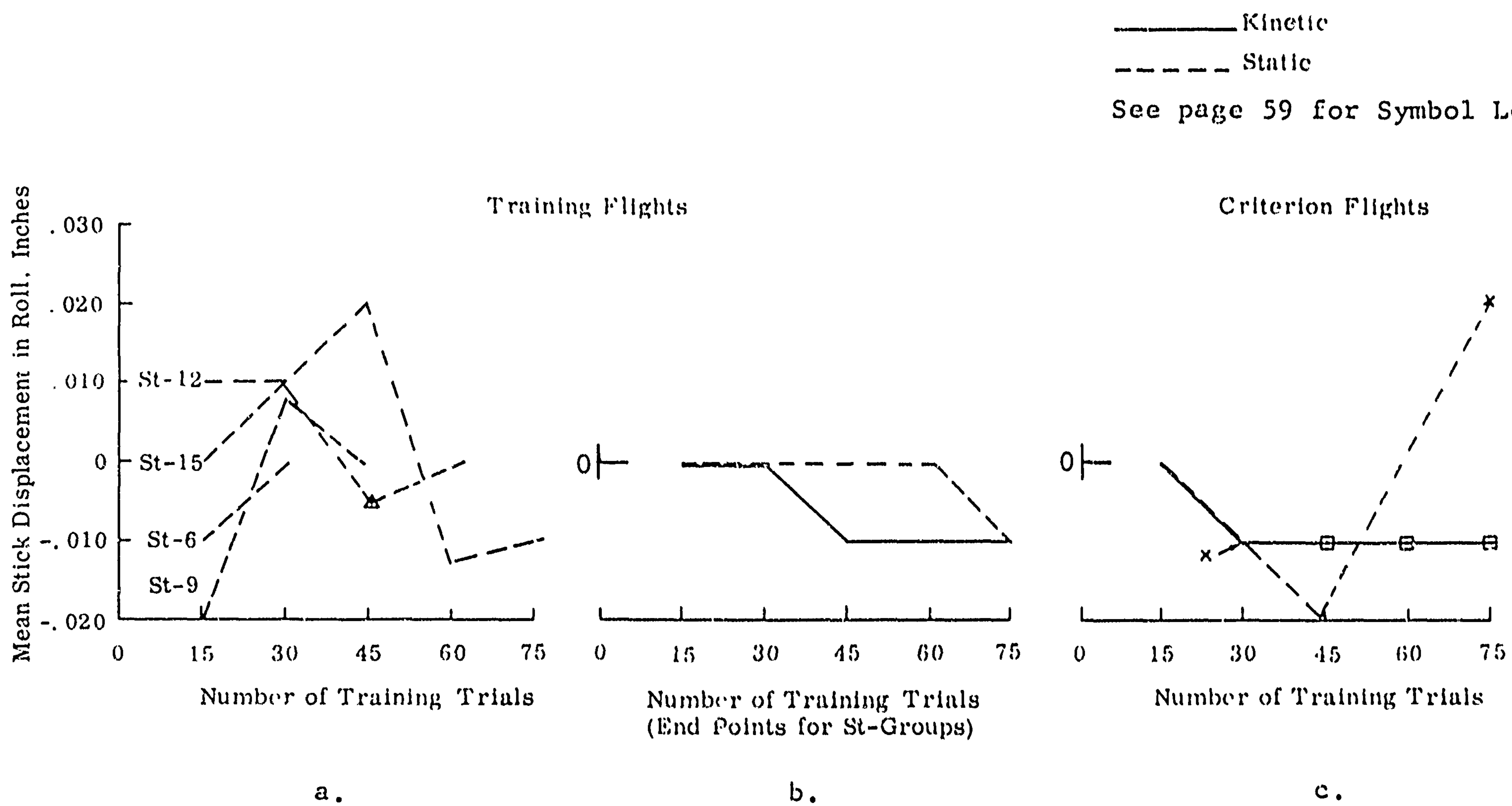

Fig. 12 Mean Stick Displacement in Roll During Training and Criterion Flights.

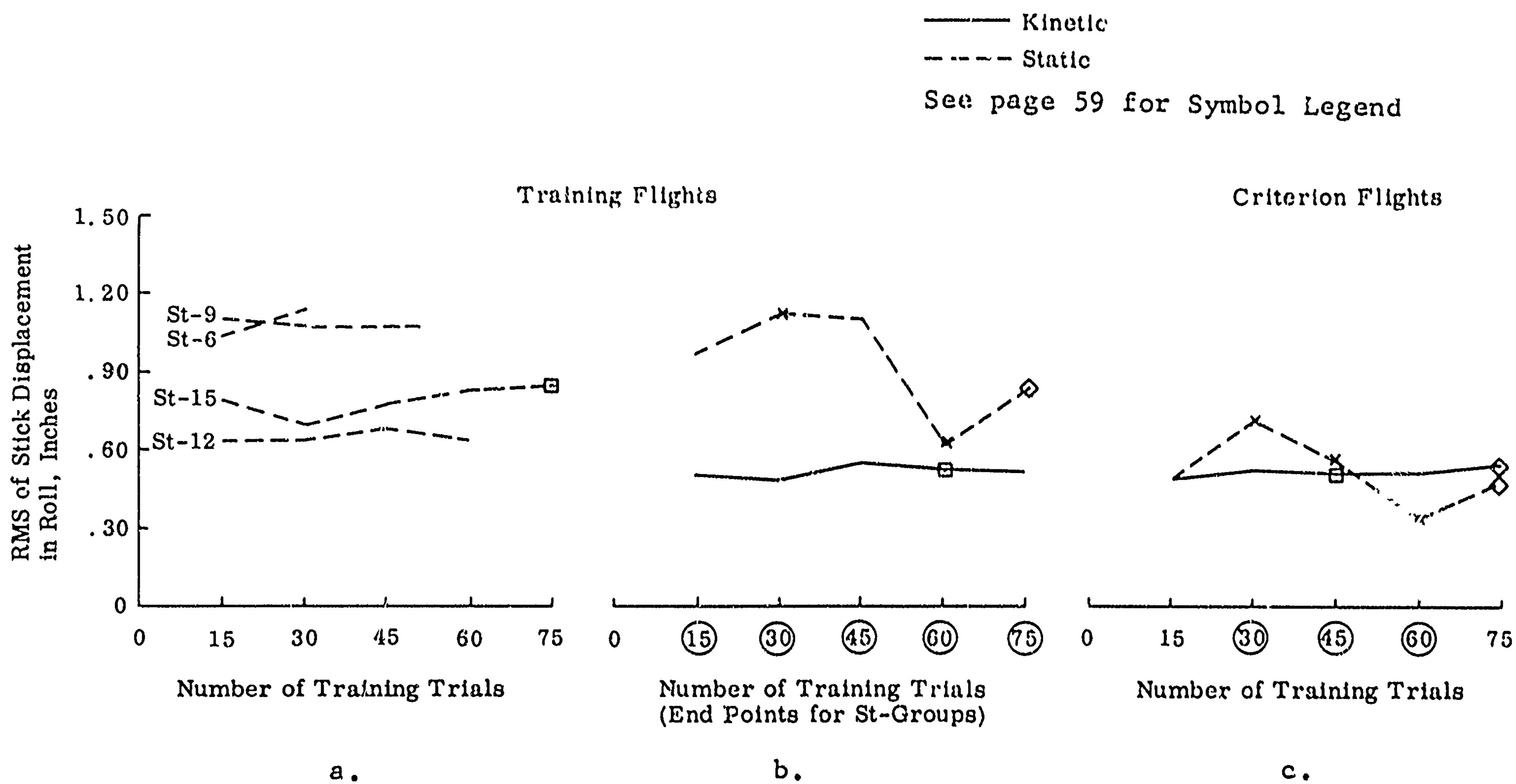

Fig. 13 RMS of Stick Displacement in Roll During Training and Criterion Flights.

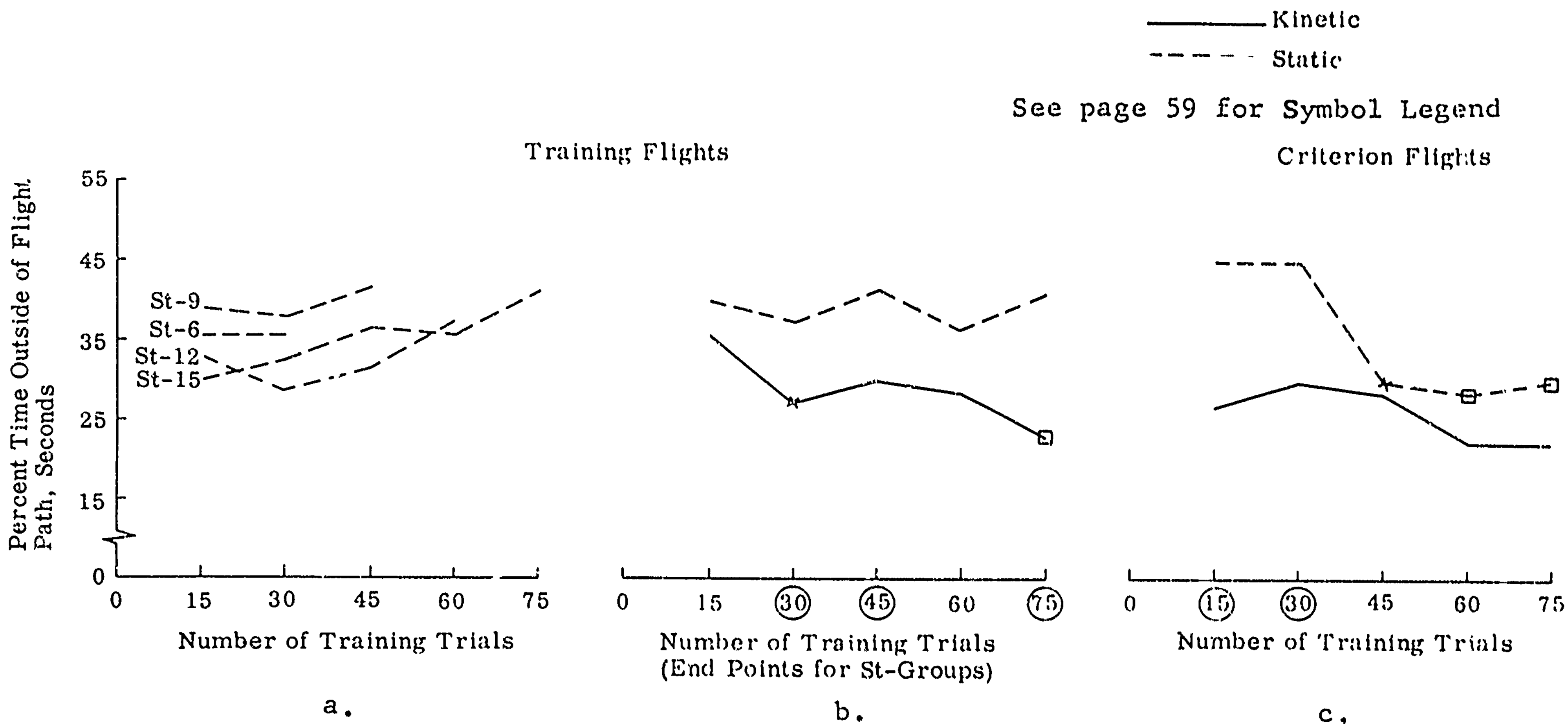

Fig. 14 Percent of Time Outside Flight Path During Training and Criterion Flights.

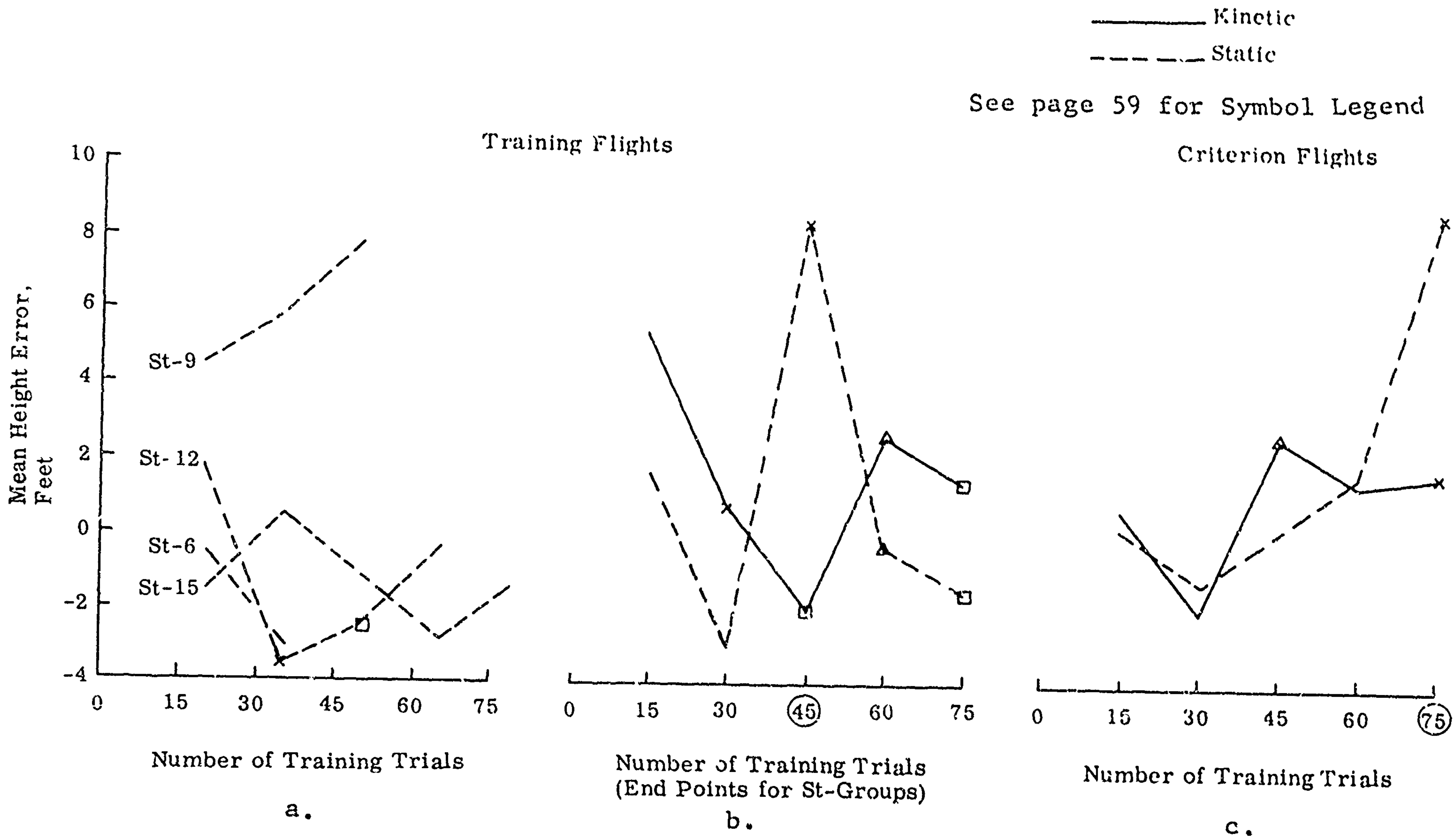

Fig. 15 Mean Height Error During Training and Criterion Flights.

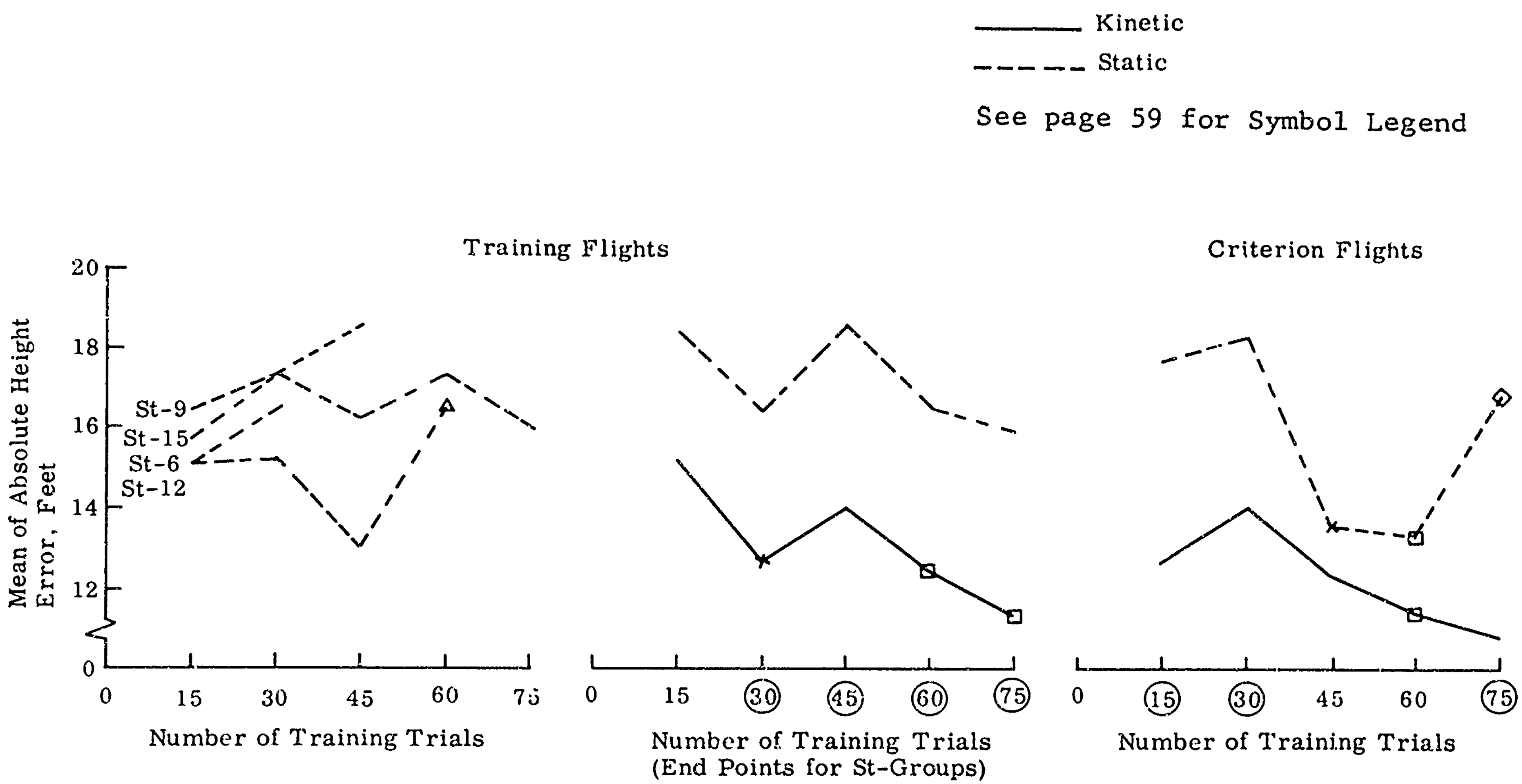

Fig. 16 Mean of Absolute Height rror During Training and Criterion Flights.

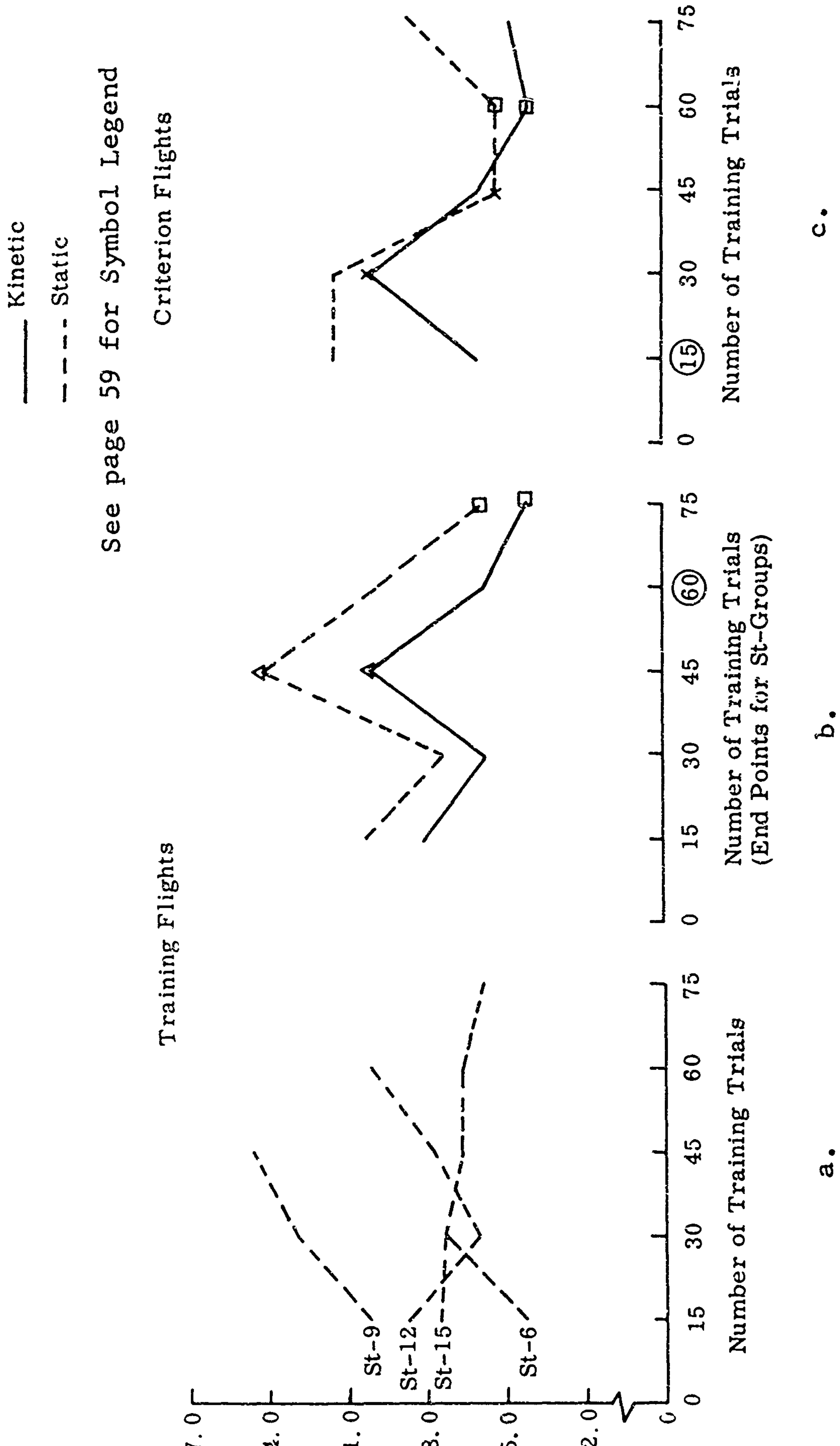

Fig. 17 RMS of Height Error During Training and Criterion Flights.

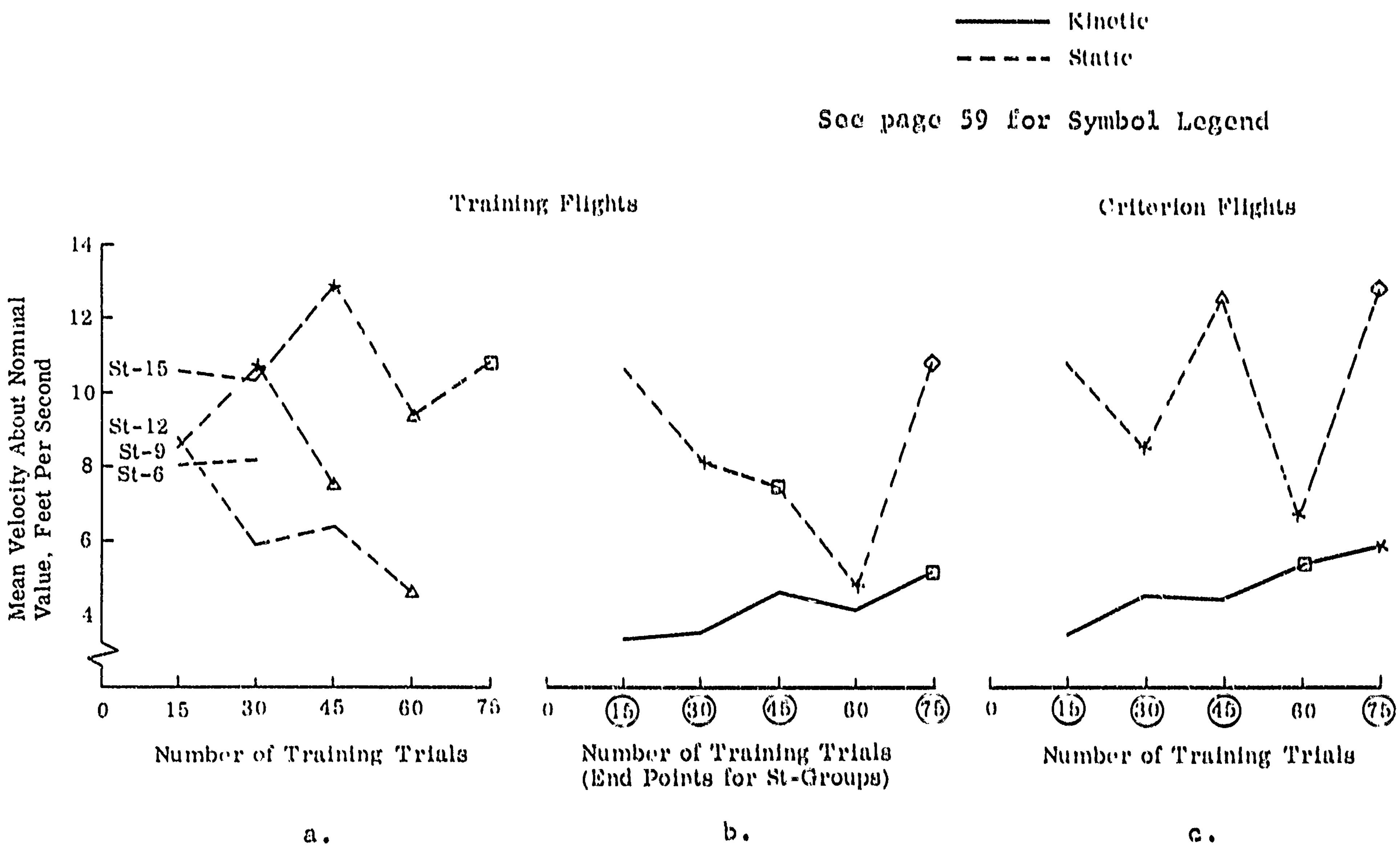

Fig. 18 Mean Velocity About Nominal Value During Training and Criterion Flights.

Fig. 18 Mean Velocity About Nominal Value During Training and Criterion Flights.

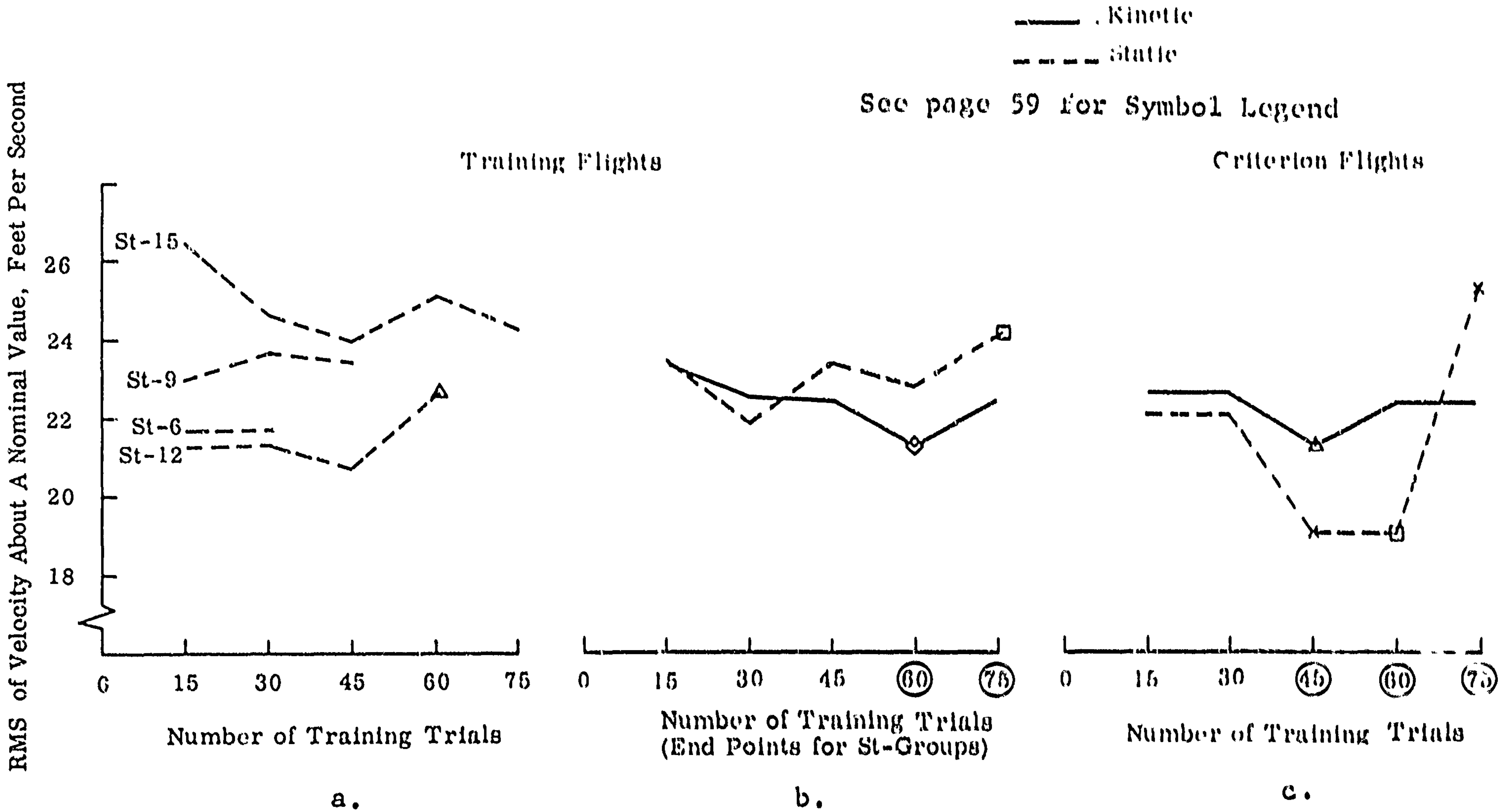

Fig. 19 RMS of Velocity About Nominal Value During Training and Criterion Flights

value was determined by calculating mean stick displacement in pitch for a near-perfect flight.

Static training seemed to separate the static groups into several levels of performance around which they each varied with no consistency or trend. The kinetic group, however, stayed at substantially the same level of performance at which they started (except for the K-75 training level). The two main groups differed from each other significantly on three of the five levels of training, both during training (Fig. 10b) and during the criterion flights (Fig. 10c). In all cases, performance of the kinetic group was better than that of the static group. Note further, that the differences are not related in any consistent manner to the number of training trials received. On the criterion flights, the static group differed from the kinetic group after 15, 30, and 45 training trials but not after 60 and 75 training flights. Thus, it appears that the level of negative transfer induced by inadequate (i.e., static) training is relatively immediate and does not increase as the time under inadequate training is increased. The fact of over-all difference between the kinetic and static groups is corroborated by results of the analysis of variance (Table 11) as is the interaction of training method and number of trials (MXT_p) that can be seen in Fig. 10c by the differing slopes for the kinetic and static groups.

2. RMS of Stick Displacement in Pitch

Figures 11a, b, c again show a picture similar to the previous one. RMS of stick displacement in pitch is higher for all the static groups than for the kinetic group. There is no consistent evidence of learning, and variability is significantly greater for the static group at all levels of training for both training and criterion flights. Anywhere from 15 to 75 static training trials induced a deterioration in performance that was relatively immediate, that did not change in a consistent direction as a function of the number of training trials, and that was not offset by the 15 criterion flights.

3. Mean Stick Displacement in Roll

Meaningful interpretation of these curves is difficult. It seems clear that the static groups spread out at different levels around which they varied fairly widely (Fig. 12a).

This wide variability accounts for the absence of between group differences during training and during criterion flights. Comparison of the static group during training and during the criterion flights shows no evidence of negative transfer. The kinetic group leveled out to a constant mean level of .01 inches of left stick while the static groups varied widely from each other, ranging from .20 inches of left stick to the same amount of right stick.

4. RMS Stick Displacement in Roll

Comparing Fig. 13a with 12a, it appears that the static groups varied in mean setting from session to session but that variability around that value was held fairly constant.

For neither the static group nor the kinetic group is there any significant evidence of learning.

During training the two main groups differed significantly from each other at every level of training (Fig. 13b) with the kinetic group showing less variability. On the criterion flights, however, the 30-trial and 45-trial statically trained groups differed significantly from the kinetic group in the direction of higher RMS (negative transfer), while at the 60-trial level the RMS was significantly lower for the static group (positive transfer). Thus, it appears that roll variability, while adversely affected by poor training simulation, is rapidly corrected when proper kinetic cueing is provided.

B. MEASUREMENTS OF SYSTEM PERFORMANCE

1. Per Cent Time Outside Flight Path (% TOFP)

Figure 14a shows no improvement with increasing training for the static group. Figure 14b shows that the static groups were significantly poorer than the comparably trained kinetic group at three of the five levels of training (30, 45, and 75 trials). When compared on criterion flights, significant negative transfer is shown for two of the five levels of training (15 and 30 trials). Results for the relative performance of the two groups during the training and criterion flights are corroborated by the analyses of variance (see Tables 8 and 19).

2. Mean Height Error

Figures 15a, b, and c convey an impression of marked individual differences and high variability. This is shown by the widely scattered points for the static groups during training (Fig. 15a). It is further reinforced by the end point plot in Fig. 15b for the static groups. Performance for the kinetic group (Fig. 15b) after the first 15 trials settled down to about plus 3 feet to minus 2 feet. There is no evidence of a constant error in the system or any of the groups as far as a propensity to land high or low is concerned. One exception to this is the tendency of the statically trained groups during training (Fig. 15a) to be low relative to the prescribed glide slope.

3. Mean Absolute Height Error

This measure gives a clearer impression of separation between the two main groups. There is, again, no evidence of learning for the static groups (Fig. 16a). There is some evidence of learning for the kinetic group (solid line Fig. 16b). Significant differences occurred between the kinetic and static groups at four of five levels of training and the differences persisted for three of the five levels during the criterion flights. All of the differences are in the direction of greater error for the statically trained pilots.

4. RMS of Height Error

This measure is closely related to the previous one of mean absolute height error, but differs from it in that it magnifies large errors and minimizes small ones. Differences between the two groups are not as marked. There is only one indication of negative transfer for the statically trained group (at the 15 training trial level—Fig. 17c).

5. Mean Velocity About Nominal Value

Figure 18a shows relatively wide individual differences and scatter in mean velocity setting. It is clear, however, that all pilots showed a consistent preference for flying above the nominal velocity. Mean performance of the kinetically trained group was closer to the correct velocity (Fig. 18b) in all cases and was significantly so for four of the five training levels. These differences resulted in significant negative transfer for four of the five training levels during their criterion flights.

6. RMS of Velocity About the Nominal Value

The curves in Fig. 19a indicate that RMS of velocity was relatively constant for each group over training trials. The intertrial comparison for the kinetic group (Fig. 19b) shows the same effect for them. The intertrial comparison for end points of the static group indicates very little variation among the static Ss. The between group (K vs S) comparisons during training shows that the RMS velocity values differed significantly after 60 and 75 trials; the kinetic group had smaller RMS values at these levels of training. The data for the transfer to criterion flights are depicted in Fig. 19c . It is interesting to note that the 45 and 60 trial groups demonstrated a positive transfer effect (less RMS of velocity than the kinetic or base line group) when transferred to the criterion flights. One training group, 75 training trials, showed negative transfer; the rest performed on a level equal to the kinetic group.

C. SUMMARY OF PILOT AND SYSTEM PERFORMANCE MEASURES

This section coordinates and briefly summarizes results of the 10 performance measures. It should be noted that the classification of data into the separate categories of system and pilot performance measures and into the categories that follow (terminal flight data, recognition data, etc.), are distinctions largely but not entirely made for convenience of presentation. Pilot and system performance are interdependent; terminal flight data are the resultant of these. It should further be pointed out that many of the measures are undoubtedly intercorrelated. Allusion has already been made to this fact in discussing mean absolute height error and RMS of height error; it is clear that %TOFP is also closely related to these two measures. Each measure nevertheless maintains a specificity and meaning of its own to warrant separate consideration. Sometimes, new insights are gained and areas for further research suggest themselves. For example, consider the data on RMS roll which, like many of the other measures, show substantial separation of the kinetic and static training group during training, but unlike the other measures, show rapid recovery (i.e., two levels of positive transfer) when motion is reinstated in the simulator. Thus there is ample reason for the separate analysis and discussions that have been presented. Here, results for all of the measures will be summarized to provide an overview.

One such overview is provided by the weighted means for all 10 measures contained in Table 21. The weighted mean was computed by multiplying the number of training trials by the performance measure after completion of the designated level of training, and after completion of the 15 criterion flights, and dividing this value by the cumulative sum of the total number of training trials. Thus, performance after 15 training trials contributed to the weighted mean one-fifth of the value contributed by performance after 75 training trials. The data show that on this measure there were significant differences between the kinetically and statically trained groups on five of the 10 measures during the criterion flights. In every case, performance of the kinetically trained group was significantly better than that of the statically trained group. Considering that all groups were initially matched, it is clear that interpolation of training without kinetic cueing disrupts performance on these measures to the point of inducing a significant decrement in skill that is not offset by 15 flights with kinetic cueing reintroduced.

Referring to the "c" subscripted graphs in Figs. 10 through 19 , and counting through all the significant differences for each level of training, it can be seen that the large preponderance of difference was in the direction of negative transfer for the statically trained groups. In only three of 50 cases was there evidence of positive transfer for the statically trained groups. There was negative transfer for these groups in 22 out of 50 cases.

Another summary of related data is shown in Table 22 below. The number of significant differences occurring on each measure for the two main groups during training and during criterion flights is shown. The mean per cent change in performance using the kinetic group as reference is shown. A minus sign indicates a decrement in performance for the static groups relative to kinetic group. Thus, during training, decrement in performance for the statically trained group occurred on all measures except mean stick displacement where no difference occurred. On the criterion flights, a mean per cent decrement occurred on every measure but two. The decrements ranged from 9 per cent (RMS roll) to 421 per cent (for mean height error). No decrement occurred in mean roll and there was a mean per cent improvement (4 per cent in RMS velocity). The consistency with

Table 21

WEIGHTED MEAN OF PERFORMANCE MEASURES FOR KINETIC AND STATIC TRAINING GROUPS DURING TRAINING AND CRITERION FLIGHTS

	Training		Criterion		
Measure	Kinetic	Static	Kinetic	Static	P[1]
1. Percent of Time Outside of Flight Path	.27	.39	.25	.33	**
2. Main Stick Displacement in Roll	.00	.00	-.01	.00	--
3. RMS of Stick Displacement in Roll	.50	.88	.51	.50	--
4. Mean Stick Displacement in Pitch	.26	.14	.25	.14	**
5. RMS of Stick Displacement in Pitch	.47	.74	.48	.67	**
6. Mean Velocity About a Nominal Value	4.43	8.19	4.99	10.27	**
7. RMS of Velocity About a Nominal Value	22.24	23.33	22.21	21.75	--
8. Mean Height Error	.84	1.32	1.29	3.23	--
9. RMS of Height Error	16.14	19.08	15.42	17.32	--
10. Mean of Absolute Height Error	12.62	16.86	11.89	15.54	**

NOTE: Probabilities noted are for criterion flights only and are derived from the analysis of variance results which are based on the arithmetic and not the weighted means. However, the differences between the arithmetic and weighted means were small. Therefore, the probabilities provide a good estimate of the significance level of the differences.

** = $p < .05$

* = $p < .01$

Table 22

NUMBER OF SIGNIFICANT DIFFERENCES AND
MEAN PER CENT CHANGE IN PERFORMANCE

	Training Flights		Criterion Flights	
Performance Measure	number	M% change*	Number of Differences	M% change*
Mean Pitch	3	-63	3	-44
RMS Pitch	5	-53	5	-40
M Roll	0	-	0	-
RMS Roll	5	-90	3	-9
Per Cent Time Outside Flight Path	3	-52	2	-59
Mean Height Error (direction ignored)	1	-313	1	-421
RMS Height Error	1	-27	1	-5
Mean Absolute Height Error	4	-34	3	-42
Mean Velocity	4	-138	4	-192
RMS Velocity	2	-7	3	+4

*from performance of K-group

which the performance decrement occurred during training carries over to the criterion flights and is further support for the preponderance of negative transfer induced by inadequate training.

D. TERMINAL FLIGHT DATA

The data presented previously were concerned with performance during the total time of carrier approach. Here, we are concerned with the question of whether a successful touchdown was achieved. The theoretical value of the previously presented data is that these were based on collation throughout the course of the flight. Terminal flight data, on the other hand, are based on position and rate measurements during only the last 1.5 seconds of the flight before touchdown. However, these data have substantial operational significance. Irrespective of performance up to the point of touchdown, the final operational concern is whether the vehicle landed successfully. A summary of the parameters used in making the determination of whether a successful touchdown was achieved are presented in Table 23 below and are based on actual flight test data. To have landed

Table 23

PARAMETERS USED IN DETERMINING THAT TOUCHDOWN WAS SUCCESSFUL[1]

Measure	Criterion Value	Limits
Vertical position	third pendant	± 8 feet
Lateral position	center line of carrier	± 40 feet about the center line
Roll angle	0°	± 7°
Pitch angle	6°	0° lower limit
Yaw angle	0°	± 9°
Rate of descent	840 feet per min	+ 1200 feet per min

[1]All measurements made at distance equal to 356 feet from touchdown because visual display requirements necessitated that flight be terminated at this point.

successfully, the vehicle had to be within the limits noted for each of the parameters. It was determined for this analysis that failure in any one parameter was tantamount to over-all failure. Tabulation was made for each flight of whether it resulted in a successful landing or a failure.

1. Analysis of Successful Touchdowns

Tables 24 and 25 show the number of successes and failures by the various groups under the conditions of training and criterion flights. It is apparent that the kinetic group was superior to the static group under most training and criterion sessions. Figure 20a is the plot of per cent of successful flights for the paired subjects during static training. The curves show no consistent trend in the direction of improvement with increasing training trials. Figure 20b is a plot of the static groups compared to the kinetic group. The kinetic group, like the static, does not show any consistent change in performance during training but does maintain a level of performance consistently above that of the static groups. Figure 20c shows successes during the criterion flights. The static groups show significant negative transfer on this variable at two of the five training trials (45 and 75 trials). Based on the assumption of matched pairs, the static subjects should have attained a level of performance equal to the kinetic subjects during the criterion flights. Since this does not happen, it is clear that static cueing affects terminal flight performance in the direction of larger errors. Note (Table 25) that for the two groups considered in aggregate, there is a significant difference in the total per cent of successful flights, the kinetically trained group achieving a 57 per cent success level compared to 39 per cent for the statically trained group.

Appendix K shows an additional analysis of the performance measures as a function of success or failure of the touchdown.

2. Analyses of Failures

Additional insight into the effects of kinetic and static training is gleaned from a detailed analysis of the failures experienced by each group. The complete analysis is shown in Appendix L. The significant data are summarized in Table 26 below. It is important to remember that this table is an analysis of the distribution of failures <u>within</u> each of the groups noted.

Table 24

PROPORTION OF SUCCESSFUL TRAINING FLIGHTS FOR KINETIC AND STATIC GROUPS AS A FUNCTION OF NUMBER OF TRAINING TRIALS

KINETIC				STATIC					
Training Trials	Total No. Flights (n =2)	No. Training Successes	%	Training Trials	Total No. Flights (n =2)	No. Training Successes	%	z	p
15	30	15	50	15	30	4	13	3.08	>.01
30	30	18	60	30	30	11	37	1.96	>.05
45	30	13	43	45	30	4	13	2.50	>.05
60	30	19	63	60	30	6	20	3.58	>.01
75	30	18	60	75	30	10	33	2.25	>.05
TOTAL	150	83	55	TOTAL	150	35	23	4.40	>.01

Table 25

PROPORTIONS OF SUCCESSFUL CRITERION FLIGHTS FOR KINETIC AND STATIC GROUPS AS A FUNCTION OF NUMBER OF TRAINING TRIALS

KINETIC			STATIC			
Training Trials	No. Criterion* Successes	%	No. Criterion* Successes	%	z	p
15	18	60	13	43	1.42	-
30	13	43	8	27	1.33	-
45	19	63	10	33	2.75	>.01
60	18	60	19	63	.25	-
75	18	60	9	30	2.50	>.05
TOTAL	86	57	59	39	2.14	>.05

*Number of Criterion Flights was 30 For Each Level of Training (N=150 per Group)

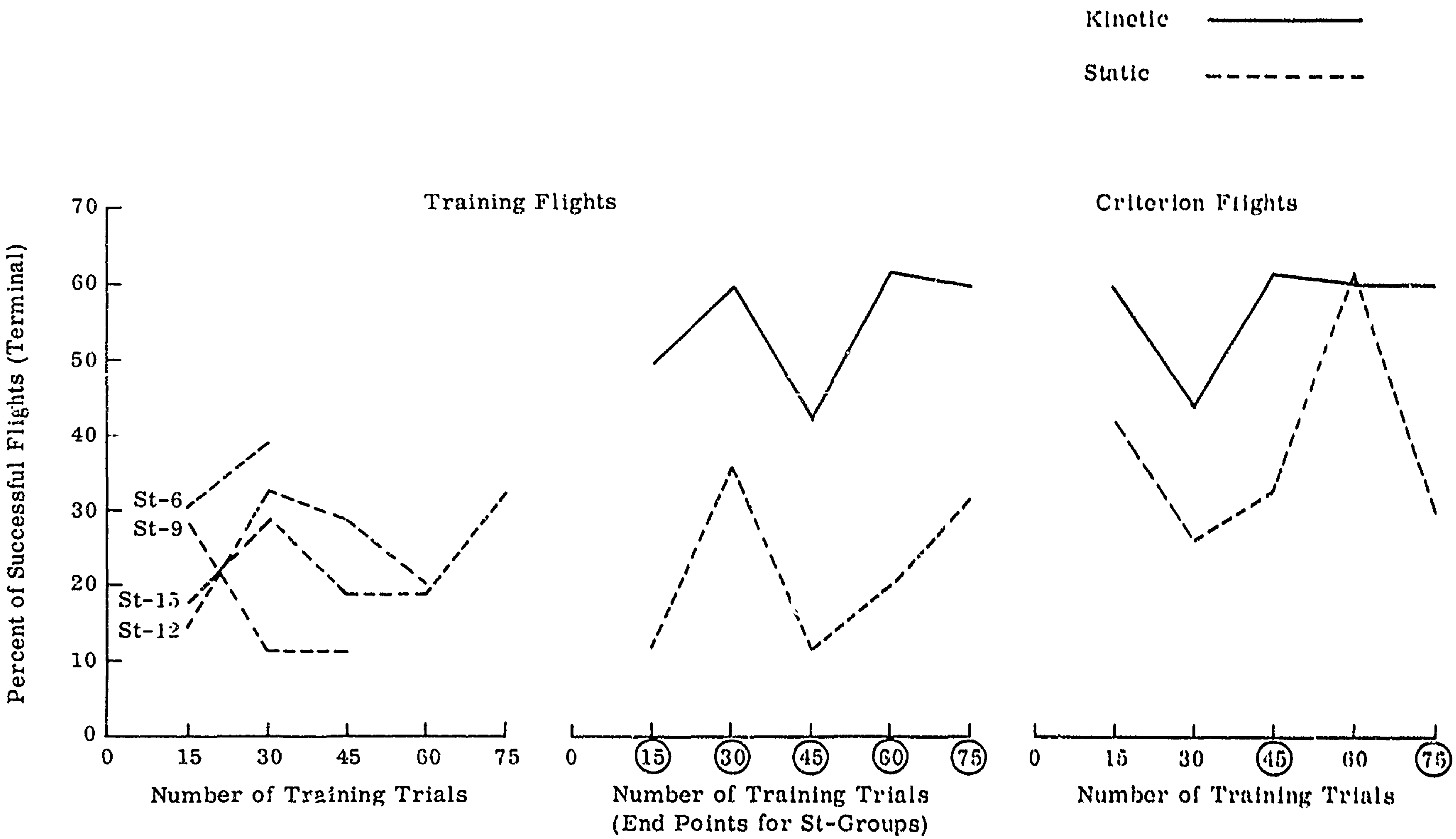

Fig. 20 Percentage of Successful Terminal Flights as a Function of Static and Kinetic Training.

Table 26

PER CENT OF TOTAL UNSUCCESSFUL FLIGHTS FOR EACH GROUP CLASSIFIED BY AXES AND TRAINING MODE

Axis	Static Training	Static Criterion	Kinetic Training and Criterion
Single Axis Failures	44.6	80.3	91.2
Multiple Axes Failures	55.4	19.7	8.8
Longitudinal Axis in any Combination	78.3	80.4	89.8
Lateral Axis in any Combination	36.3	33.9	13.3
Body Axis in any Combination	58.8	14.4	5.7

The table shows that for the three groups, the longitudinal axis is the largest over-all contribution to the unsuccessful flights. It further shows that 55 per cent of the unsuccessful flights of the static training group during training flights involved more than one axis compared to 19.7 per cent during their criterion flights and to 8.8 per cent for the kinetically trained group. The implication of this fact is that the static training group "failures" were more catastrophic and involved a greater loss of control of the vehicle than was true for the kinetically trained group.

A third noteworthy fact to emerge from this failure analysis is the relatively much higher influence that the body axes (pitch, roll, and yaw) had on the failures for the static group as compared to the kinetic group. The static training group showed 58.8 per cent of its failures involved body axes measures, alone and in combination. This figure dropped to 14.4 per cent when the static group went onto the criterion. This is still considerably higher than the 5.7 per cent noted for the kinetic groups' flights. It can be seen from the detailed data in Appendix L that most of the body axis failuresare attributable to pilot pitch and roll inputs and not much to yaw.

In summary, it seems clear that kinetic cueing has a marked effect on system performance measured in terms of terminal flight performance and that the degree of loss of control, where a failure occurs, is much more widespread when the pilot does not have motion simulation in the trainer. Moreover, these facts persist for at least the 15 criterion flights (i.e., full-motion cueing) given the static groups upon completion of training. In other words, the effects of improper training are not counteracted immediately.

E. RECOGNITION OF FAILURE REGIMES

For somewhat more than one-half of the flights, the pilots were asked, at the termination of each flight, to identify verbally the regime just flown. As an aid to this process, a card with the code letter and name of each regime (as noted elsewhere in this report) was taped to the lower right corner of the instrument panel. Knowledge of the results of these judgments was not given to the pilots. A summary of the results of these data is shown in Table 27 which follows.

It can be seen that over-all accuracy of detection was 10 per cent better during the kinetic flights (44 per cent) than during the static flights (34 per cent).

Analysis by individual regime shows that most of this difference is accounted for by the "B"-failure, i.e., failure of the automatic pitch stabilization system. It can be seen that it alone differed significantly as a function of whether the detection was made during a kinetic (40 per cent) or static (15 per cent) flight. It should be noted that this failure is one of experimental interest (i.e., not included just to control habituation) that was selected as being most closely related to vehicle dynamics, i.e., most dependent on kinetic cueing. Thus, the significant difference in detection accuracy for this failure could be interpreted as indicating that kinetic cueing does provide specific information about the nature of the failure. There are, however, substantial facts weighing against this conclusion. For example, emphasis could be placed on the fact that for only one of the nine regimes did kinetic cueing apparently provide specific information. The point should also be considered that the pilots made their judgment at the <u>end</u> of each flight. Thus, the pilots had feedback on results of their control actions during the whole flight as an

Table 27

NUMBER OF PRESENTATIONS AND DETECTIONS OF EACH OF THE FAILURE REGIMES

	Static Flights			Kinetic Flights			
	Number			Number			
Failure Regime	Presented	Correctly Detected	Per Cent Correct	Presented	Correctly Detected	Per Cent Correct	P
A	57	21	37	48	23	48	-
B	55	8	15	47	19	40	$<$ .01
C	56	9	16	45	11	24	-
D	58	26	45	50	24	48	-
E	12	5	42	8	6	75	-
F	9	9	100	9	9	100	-
G	13	12	92	10	8	80	-
H	12	6	50	12	5	42	-
I	11	1	9	9	0	0	-
All Regimes	283	97	34	238	105	44	$<$ .05

additional aid to refining their judgment as to what the particular failure regime was. Finally, weighing against the "specific information" hypothesis is the overwhelming evidence from the performance measures where failure regimes rarely contributed at a statistically significant level. Regardless of these considerations, these recognition data necessitate that one conclusion be somewhat qualified; namely, that motion provides general alerting of the pilot rather than specific information about the condition of the vehicle.

F. OPINION QUESTIONNAIRE DATA

A 27-item questionnaire (see Appendix F) was given to each of the 12 subjects at the conclusion of their flights. The questionnaire was so constructed that a normal distribution of item scores was derived from each subject's responses. The continuum of values was "highly applicable," "applicable," "neither," "inapplicable," and "highly inapplicable." Of the total of 27 questions, the pilots were asked to designate three items as "highly applicable," three as "highly inapplicable," five as "applicable," five as "inapplicable," and 11 as "neither." The questions answered at the ends of continuum (either "highly applicable" or "highly inapplicable") were of chief concern as they represented the strongest attitudes toward the items under consideration. It was decided therefore to take the three most "highly applicable" items and the three most "highly inapplicable" items as answered by the group for detailed analysis. In the discussion that follows, the items are discussed in rank order of their scoring weight. The scale weights for each of these categories were as follows:

Highly Applicable	Applicable	Neither	Inapplicable	Highly Inapplicable
3	1	0	-1	-3

The algebraic sum determined whether the statement was accepted positively (highly applicable) or negatively (highly inapplicable).

1. Highly Applicable Statements

a. The flights required my total concentration. This statement was answered as highly applicable by 8 of 10 statically trained pilots but was not so selected by either of the kinetically trained pilots. This fact reflects, perhaps, the need for greater visual attention by the static group. This explanation would conform with the hypothesis that during the kinetic flights, the pilot could relax to a relatively greater degree, because he could rely on the "seat-of-his-pants" to alert him to an incipient emergency.

b. The over-all simulation was good. A majority of the subjects felt that the over-all handling and visual characteristics of the system were better than average. There was no split of responses into static or kinetic training. This attitude of positive acceptance was reflected in the enthusiasm and cooperativeness that was typical of the pilots who took part in the program.

c. I enjoyed the experiment. This statement received the third highest score. It was an opinion offered by both groups (kinetic and static), and further confirms the high level of motivation to which we previously alluded.

2. Highly Inapplicable Statements

a. It was quite easy to discriminate among the different emergencies. This negative report supported the empirical evidence that the emergency tasks were of a difficult nature. Consider, for example, the fact that the recognition data previously discussed showed that the best over-all detection capability only reached 44 per cent.

b. The simulated meatball conveyed the necessary information. It seemed to disturb most pilots that the simulated meatball was not a direct analog of a carrier meatball. The departure from realism may have been disconcerting in an aesthetic sense. Objectively, the meatball used was quite accurate and sensitive to small altitude changes. However, the contrast ratio and the small number of TV lines occupied by the bar did obscure exact relationships at the furthest distance from the carrier.

c. The throttle control was realistic. Some of the subjects voiced the opinion that the lag in response to power lever movements was too great. This was probably due more to the subjects' lack of experience with a jet aircraft of this configuration than to an unnatural response lag since care was taken to provide realistic equations of motion. Some of the pilots did not have extensive jet experience and they may have been habituated to expect the quick response characteristics of reciprocating engines. This inability to adapt to the lag characteristics of the power lever probably accounts for the very high RMS velocity scores reported earlier in this report.

In terms of the items discussed above, it appears reasonable to state that the pilots were highly motivated to participate in an experiment that they felt presented a challenging task. While they regarded the over-all simulation facility as "good," they were still critical of some minor faults.

SECTION VI

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine if kinetic cueing is of value in learning to control an airborne vehicle. A carrier landing mission was selected as the basic task configuration. The Grumman Vehicle Motion Research Simulator was used as the basic test equipment. Analog computers were used to program the dynamics of a typical, high performance, carrier-based jet aircraft. Four failure regimes, varying in terms of apparent intrinsic dependence on vehicle dynamics, were programmed and presented to the pilots in a randomly determined order. An additional five regimes were included to control pilot habituation to order of presentation.

A new experimental technique, serial pick-off, was used. It offers two primary advantages, one, economy of necessary subjects without loss of data and, two, a more correct emphasis on determining rate of change on the criterion <u>before</u> learning, if any, is completed. Essentially, the method as applied to our study required matching of pairs of pilots in terms of initial ability on the simulator. One pair was assigned to the kinetic training condition. The remaining pairs were assigned to one of the five levels of static training. After completion of the pre-determined levels of training, performance of the statically trained group was compared to that of the kinetically trained (control) group.

The two training conditions were <u>identical</u> in all particulars except for the absence of cockpit accelerations (or kinetic cueing) during the static training condition. During each flight, various measures of system and pilot performance were collected. Within the conditions of the experiment as outlined above, the primary conclusions are as follows:

1. Kinetic cueing is a valuable adjunct to airborne vehicle simulation systems. Performance during criterion flights was consistently superior for the kinetically trained group, often at levels well beyond chance expectancy. Illustrative of this statement, absolute altitude error, per cent of time outside the correct flight path, variability of stick dis-

placements and average conformity to command or optimum settings were significantly better for the kinetically trained pilots. Moreover, the total proportion of successful touchdowns was significantly greater for the kinetically trained pilots. Finally, unsuccessful approaches showed more widespread error (i.e., caused by multiple reasons) much more frequently for the statically trained than for the kinetically trained pilots.

2. The superiority of kinetic training did not seem generally to be significantly related to the kind of emergency regime simulated. This fact supports the inference that kinetic cueing seems to increase pilot alertness rather than provide specific information regarding details of vehicle dynamics. This conclusion is somewhat qualified by the fact that the failure regimes did show a significant effect on two performance measures and by the fact that one of the nine failure regimes was correctly recognized significantly more often under kinetic conditions.

3. There was no appreciable evidence of positive learning for either main experimental group. There is some indication that this may well be due to the fact that learning was completed during the familiarization and the first 15 training trials. It may also be due to the relatively high skill level of the pilots used in this study.

4. Corollary to the immediately preceding conclusion, superiority of the kinetic training condition manifested itself because of deterioration in the performance scores of the statically trained pilots. These pilots usually showed performance decrements after the first 15 training trials and the magnitude of these decrements did not generally change in any consistent manner with additional training trials. Moreover, the decrement persisted for the 15 criterion flights (i.e., after kinetic cueing was reinstated). Stated another way, results indicate that 75 trials of static training did not on the average equal 15 trials of kinetic training.

SECTION VII

RECOMMENDATIONS

Within the context of the conditions of this study, there is clear evidence that kinetic cueing is an important and highly desirable feature that should be incorporated into operational flight trainers. There is evidence that, at least for experienced pilots, the absence of realistic motion acceleration induces a relatively lasting degradation in performance. Moreover it appears that kinetic cueing should be provided when training pilots to react to emergencies even if the nature of the emergency is initially unrelated to the dynamics of the vehicle.

To state that trainers should incorporate kinetic cueing is a rather gross specification. It was beyond the scope of this study to determine if this recommendation is qualified by the skill level of the potential trainee or to determine the degree of cueing fidelity that should be designed into the trainer. There are data in this study that suggest the need for further investigation of these two factors. Consider, for example, that roll variability was very significantly higher during training for the statically trained pilots; yet, unlike other measures, the variability disappeared readily when kinetic cueing was reinstated. Additional questions not considered in this study should be investigated; e.g., what in the visual field does the pilot attend to? Which elements of the visual simulation system are important? Is visual scan pattern related to pilot efficiency? Does kinetic cueing have the effects noted in this study because it changes pilots' scan behavior? It is recommended that studies to answer these questions be undertaken in the context of applying the results to the population of potential trainees for the range of likely mission configurations.

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